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RESOURCE AND ENVIRONMENTAL IMPACTS OF TRENDS IN U.S. AGRICULTURE

by

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Resources for the Future
Washington, D.C. 20036

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16. ABSTRACT

Trends in demand for U.S. agricultural production and in agricultural technology suggest increasing pressure on the nation's land and water resources over the next several decades. The expected consequences would be rising economic costs of production and damages to the environment. This study analyzes those trends, assesses their economic and environmental impacts and discusses policies for dealing with their impacts.

The quantities of land, water and other resources farmers use to increase production depend basically on the kinds of technologies they employ. Two categories of technology are distinguished--land-using technologies and land-saving technologies. Farmers' choices from the spectrum of technologies are conditioned by the prices and productivities of the alternatives.

Analysis of trends indicates that an additional 60 to 70 million acres will be brought into production and that erosion will emerge as the most serious environmental problem of agriculture. A slower rise in inputs of fertilizer per acre is expected and the total quantity of insecticide applied to crops should decline. Herbicide use is expected to increase markedly. New land-saving technologies could reduce pressures on the land.

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FOREWORD

Environmental protection efforts are increasingly directed towards preventing adverse health and ecological effects associated with specific compounds of natural or human origin. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, management or engineering tools are developed for addressing water quality problems with emphasis on assessing potential exposures to chemical contaminants.

Crop production practices, already significant sources of water and air pollution, represent areas of increasing environmental concern as agricultural demands increase pressures on the nation's land and water resources. This report identifies and assesses the relative importance of nation-wide trends in agricultural production and technology that may have significant effects on the environment over the next several decades. Study findings are intended to aid environmental managers as they attempt to anticipate pollution problems of the future.

David W. Duttweiler
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PREFACE

This report is the culmination of several years of research undertaken at Resources for the Future. The study originated out of concern that prospective long-term trends in demand for U.S. agricultural production, in prices of energy and other key inputs, and in agricultural technologies would put increasing pressure on the nation's land and water resources and on the environment. It appeared to us that these trends likely would shift the agricultural situation of the United States from one of chronic surplus to one of recurring if not chronic scarcity. Should such a shift occur the nation likely will require major modification of the policies for resource and environmental management which have evolved since the 1930s.

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The study is in five parts: (1) projections to 1985, 1990, and 2010 of production of wheat, feed grains (corn, grain sorghum, oats, and barley), soybeans and cotton (section 1); (2) analysis of trends in input prices, technology, and crop yields as a basis for projecting the demand for cropland (sections 2-4); (3) analysis of trends in fertilizer and insect management practices and in tillage technologies as a basis for projections of demand for fertilizers and pesticides (section 5); (4) analysis of the environmental impacts of the projected quantities of resources to reach judgments about the future severity of the impacts (section 6); (5) assessment of the effectiveness of current policies for dealing with the prospective environmental problems and discussion of alternative policies where these appear needed. State planning done under Section 208 of the Federal Water Pollution Control Act gets special attention in this part (section 7).

Given the objectives of the study, we aimed at comprehensiveness in two senses: (1) we focused on the nation as a whole, although considerable attention is given to regional and state issues; (2) we deal with all major environmental impacts of crop production, meaning erosion, fertilizer and pesticide pollution, and soil and water salinity associated with irrigation. Being comprehensive and undertaken with a relatively modest commitment of resources, the research necessarily is cast at a high level of generality. The intent is to identify and assess the relative importance of trends in agricultural production and technology that, from a national perspective, may have significant effects on the environment over the next several decades. Given this perspective and time frame, the conclusions of the research necessarily are subject to greater uncertainty than would be the case if the time span were shorter and the focus more narrow. The conclusions, therefore, about trends in technology, resource use, environmental impacts, and policies are not intended to apply to specific local situations. The conclusions should be meaningful and useful, however, in providing insights as to emerging environmental problems of agriculture and the effectiveness of policy and institutional modes of dealing with them.

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Preface 2

With the exception of interviews conducted as part of our research on tillage and pest management technologies, irrigation and 208 planning, we have not developed new sources of data. Rather we have relied on systematic surveys of data and other information already available elsewhere. Nor have we developed formal models of the various relationships studied. We did, however, make use of Iowa State University's model of U.S. agriculture to project erosion and of a model developed at RFF for another purpose to transform projections of erosion to projections of sediment delivered. With these exceptions the analysis is not cast in a formal modeling mode. This would not have been appropriate, in our judgment, given the broad focus of the research and its intent to identify and assess new patterns of resource use and technology likely to emerge over several decades.

The research was partially funded by a grant from the Environmental Protection Agency's Environmental Laboratory at Athens, Georgia as part of the Laboratory's program of research on Environmental Implications of Trends in Agriculture. Previously published research under this program are: Development Planning and Research Associates, Inc., Environmental Implications of Trends in Agriculture and Silviculture, Vol. I: Trend Identification and Evaluation by S. Unger, EPA-600/3-77-121 (1977); Vol. II: Environmental Effects of Trends by S. Unger, EPA 600/3-78-102 (1978); Vol. III: Regional Crop Production Trends by S. Unger, EPA 600/3-79-047 (1979). Also F. C. White et al., Environmental and Economic Impact of Agricultural Land Use Conversion: an Evaluation Methodology, EPA 600/5-80-002 (1980); R. W. Skaggs, J. W. Gilliam, T. J. Sheets and J. S. Barnes, Effect of Agricultural Land Development on Drainage Waters in the North Carolina Tidewater Region, Water Resources Institute of North Carolina, WRR/Report no. 134 and EPA 600/3-80-087.

Two other studies financed partially under the Athens Laboratory's "Trends" program were undertaken at Resources for the Future simultaneously with this one. One, with the general title Trends in U.S. Irrigation: Three Regional Studies (Pierre Crosson, project leader, 1981) included Western Irrigation: Its Past and Future Growth, by Kenneth D. Frederick with James C. Hanson; Growth and Prospects for Irrigation in the Eastern United States, by James C. Hanson and James Pagano; The Economic Potential for the Expansion of Irrigation in the Mississippi Delta Region, by R. N. Shulstad, R. May, B. Herrington and J. Erstine. The study by Shulstad et al. was done at the University of Arkansas under a grant from Resources for the Future.

The second companion RFF study was Conservation Tillage and Conventional Tillage: a Comparative Assessment, by Pierre Crosson, published by the Soil Conservation Society of America, Ankeny, Iowa (1981).

ABSTRACT

Trends in demand for U.S. Agricultural production and in agricultural technology suggest increasing pressure on the nation's land and water resources over the next several decades. The consequence would be rising economic costs of production and damages to the environment. The study analyzes and projects those trends, assesses their economic and environmental impacts and discusses policies for dealing with the impacts.

those

Rising demand for exports of grains and soybeans is a principal source of increasing pressure on the resource base. Demand for corn to produce ethanol will increase, but by a relatively small amount relative to export demand. Other components of domestic demand will increase primarily in response to population growth, expected to be less than 1 percent annually from 1980 to 2010.

The quantities of land, water and other resources farmers use to increase production depend basically on the kinds of technologies they employ. Two categories of technology are distinguished, those combining relatively large amounts of land with non-land inputs (land-using technologies) and those for which the ratio of land to non-land inputs is relatively low (land-saving technologies). Alternative technologies are thought of as lying along a spectrum, with highly land-using technologies at one end and highly land-saving technologies at the other.

Farmers' choices from the spectrum of technologies are conditioned by the prices and productivities of the alternatives. From the end of World War II to the early 1970s relatively low prices of energy and fertilizers and the high productivity of these inputs favored choices from the land-saving end of the spectrum. Crop yields and total productivity rose at unprecedented rates and the acreage of land in crops declined.

After the early 1970s real prices of energy and fertilizers rose and the rate of increase of total productivity slowed. Farmers shifted toward the land-using end of the spectrum, and crop yields increased much more slowly than in the two decades previous to the early 1970s.

The consensus is that real energy prices will continue to rise, and there is much evidence that fertilizer prices will also. These trends, combined with increasing scarcity of water for irrigation in the West, imply that farmers will continue to favor land-using technologies unless new land-saving technologies are developed.

The anlysis of trends in technology indicates that an additional 60 to 70 million acres of land will have to be brought under crops to meet

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Abstract

projected crop demand in 2010. This increase, combined with rising demand for agricultural land for urban and other non-agricultural uses, suggests increasing real economic costs of agricultural land.

Inputs per acre of fertilizer are expected to rise, but at the relatively slow pace experienced since the early 1970s rather than at the high rate characteristic of earlier years. The total quantity of insecticides applied to crops is expected to decline despite more acreage because of a sharp reduction in per acre applications of insecticides to cotton. Per acre applications to corn also are expected to decline, but not so rapidly as for cotton. Herbicide usage is expected to increase markedly because of more acres in crops and because of increased per acre applications reflecting the spread of conservation tillage.

The projected quantities and pattern of resource use suggests that erosion will emerge as the most serious environmental problem of agriculture. Sheet and rill erosion from cropland is projected at 3.5 billion tons in 2010, compared with 1.9 billion tons in 1977. Per acre erosion would rise from 4.7 tons to 7.4 tons, 2.4 tons more than the maximum set by the Soil Conservation Service as consistent with maintaining long run productivity of the land. Sediment delivered to the nation's rivers, lakes and reservoirs would double. It is likely that erosion on the projected scale would be viewed as posing a significant threat to national water quality as well as to the productivity of the land.

The nation traditionally has relied on voluntary approaches to erosion control, offering farmers financial inducements, e.g. cost sharing of erosion control practices, to enlist their participation in control programs. This approach works reasonably well when commodity markets are weak, but when they are strong, as expected over the next several decades, then farmers have incentive for intensive use of their land. They are reluctant to adopt erosion control measures if these require setting aside land which could be in production.

Section 208 of the Clean Water Act Amendments of 1972 authorizes the EPA, acting through the states, to regulate non-point pollution to achieve improved water quality. Section 208 thus seems to convey authority to the EPA to impose erosion controls where erosion threatens water quality. State plans drawn up under Section 208, however, rely on traditional voluntary approaches to erosion control, and the EPA has accepted this.

If the erosion problem emerges as projected, traditional voluntary approaches likely will be perceived as inadequate. New programs involving penalties for farmers not in compliance with erosion standards may be needed; and better targeting of programs on the worst offenders would have high payoff. Departures from the voluntary approach will be resisted, however, and both their political and administrative costs likely will be high. This does not mean that new departures should not be developed. It suggests, however, that they be accompanied by a strategy of research to develop new technologies that serve both the farmers' economic interest and the social interest in reducing environmental damages. New land-saving technologies that substitute other inputs for high priced fossil energy and fertilizer would

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reduce pressure on the land. Enhanced photosynthetic efficiency in main crops and expansion of their capacity to biologically fix nitrogen are examples. Development of a higher yielding variety of soybean is another. Research to extend the economic limits of conservation tillage would make it possible to use this technology on land where it now is not competitive, thus significantly reducing the threat of erosion. However, the reliance of conservation tillage on herbicides for weed control indicates that research to extend the technology should include careful study of the long term environmental effects of high levels of herbicide use.

This report was submitted in fulfillment of Grant No. R8060236010 by Resources for the Future under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1978 to December 1980 , and work was completed as of June 1981.

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Pierre Crosson
Sterling Brubaker

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CONCLUSIONS

Trends in demand for agricultural production and technology suggest that pressure on the nation's land and water resources and on the environment will increase over the next several decades. Erosion damages likely will be viewed as posing a more serious threat to the environment than fertilizers, pesticides or salinity resulting from irrigation. Except for a few "hot spots" in California and Nebraska, concentrations of nitrate-N in groundwater is not now a serious problem. Nitrates in rivers and streams generally are less than the Public Health Service's standard of 10 ppm except occasionally in some small mid-western streams.

Consumption of nitrogen fertilizer is expected to increase, but because of its rising price farmers will have incentive to increase the efficiency of use. Losses of nitrates to water bodies, therefore, should increase proportionally much less than the increase in nitrogen applied. Nonetheless, the projected increase in some regions, e.g. the Southeast, is so large that nitrates entering water bodies may cause some problems.

Phosphorus is the main contributor to accelerated eutrophication. Municipal and industrial sources contribute more phosphorus to surface waters than agriculture. Steps already under way to reduce phosphorus discharges by municipalities and industry are expected to ease the eutrophication problem. Projections of increased use of phosphorus fertilizers suggest that any additional phosphorus reaching surface waters from this source will be small compared to reductons from municipal and industrial sources.

Cotton production is shifting from the Southeast and Mississippi Delta, where per acre application of insecticides is high, to Texas, where it is low. In addition, integrated pest management (IPM), meaning primarily increased use of consultants to advise on the timing and amount of insecticide use, is spreading in the Delta and Southeast. IPM involves the marginal substitution of knowledge of plant-insect interactions for rule-of-thumb spraying, and aims at keeping insect damage below the economic threshold, not at eliminating damage completely. The result is more sparing use of insecticides for a given level of control. IPM also has potential for dealing with corn insect pests.

Cotton and corn together accounted for 60 percent of all insecticides applied to crops in 1976. Trends in the location of cotton production and in insect management practices on cotton and corn thus suggest a significant decline in total insecticide use, even though corn acreage (but not cotton) is expected to increase.

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Since the late 1960s farmers have been substituting organophospherus and carbamate insecticides for the organochlorines. This increases the danger of acute toxic effects on humans and other non-target species but reduces the more subtle and pervasive but less lethal effects of the organochlorines. The outcome could be reduced environmental pressure because the effects of the organophosphorus and carbamate compounds are readily detectable and therefore easier to deal with.

Because of the projected decline in total insecticides applied and change in the nature of the materials used the environmental threat of insecticides is expected to lessen.

Herbicide use will increase substantially because of increased acreage and the spread of conservation tillage. On present evidence this increase does not appear to pose a significantly greater environmental threat. However, some potential pathways by which herbicides may impact on the environment have not been investigated. Consequently the possibility of increased environmental damages from herbicides cannot be dismissed.

The expansion of land in crops implies an increase in sheet and rill erosion from cropland from 1.9 billion tons in 1977 to 3.5 billion tons in 2010. Per acre erosion would rise from 4.7 tons to 7.4 tons, and sediment delivered to surface waters would about double. Erosion on this scale likely would be viewed as a major threat to water quality and perhaps also to the long-term productivity of the land. The traditional voluntary approaches to erosion control likely will be judged inadequate. Regulatory programs involving penalties for farmers exceeding erosion standards may be necessary. Such programs will incur high political and administrative costs. Consequently a policy to invest in development of new technologies which are both higher yielding and less environmentall damaging than current technologies could have high social pay-off.

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RECOMMENDATIONS FOR RESEARCH

The study demonstrates that trends in demand for agricultural production and in technology fundamentally determine the prospects for resource use and environmental damage in American agriculture. Given the growth of demand, the expected increase in pressure on the resource base and on the environment reflects the prospect that technological change will be relatively land-using and total productivity growth relatively slow. This suggests high social payoff to a research strategy to develop new technologies that are higher yielding and have higher total productivity than those now in prospect. Such technologies not only would restrain the rise in economic costs of agricultural production which now seems in prospect, they also would ease pressure on the environment by reducing the amount of land needed to meet projected demand for production. The projected increase in cropland implies a substantial increase in erosion, which this study concludes is the major future threat to the environment from agriculture.

The social payoff to an appropriate research strategy would be even higher if, in addition to high yields and high total productivity, the new technologies also incorporate features specifically designed to reduce pressure on the environment.

It is easier to make the general case for increased investment in research to develop new technologies than to specify the particular lines the research should pursue. Four lines look promising:

1. Increasing yields and total productivity requires that the amount of energy combined with the land must increase, or that the efficiency of energy used should rise. The prospective increases in real prices of energy and fertilizers indicate that simply increasing the amounts of these resources per acre of land is not the way to go. There is potential for increasing the efficiency with which energy and fertilizer are used, but this potential already is incorporated in the projections in this study.

Improvements in the photosynthetic capacity of main crops to capture and convert the sun's energy into valuable plant material would increase yields without requiring proportional increases in inputs of purchased energy and fertilizer. Improvements in photosynthesis also would increase the attractiveness of enhancing the capacity of plants (and related microorganisms) to biologically fix nitrogen. Biologically fixed nitrogen, of course, could substitute for increasingly expensive nitrogen fertilizers. However, increasing the plant's capacity to biologically fix nitrogen would demand more plant energy. If photosynthetic efficiency were not improved, meeting the nitrogen fixing demand for energy would reduce the supply available for valuable plant growth. In this case, crop yields might

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be less with enhanced biological nitrogen fixation than if purchased fertilizers provided the necessary nitrogen.

Research on photosynthesis and biological nitrogen fixation was not given high priority in the U.S. over the last several decades, perhaps because the main problem in American agriculture appeared to be too much productivity rather than too little. A consequence is that the nation's capacity to markedly increase research in these two areas is limited by scarcity of the necessary scientific talent. In addition, the modest amount of research conducted so far means that there are large gaps in basic scientific knowledge that must be filled before research can move to the stage of developing new economically attractive technologies. Investment in research in these two areas, therefore, does not promise quick returns.

2. Plant breeding to develop higher yielding varieties of main crops has been a main source of higher yields and total productivity. There are promising lines still to be pursued in this area of research. Soybeans are a major land using crop for which demand is rapidly increasing. In this study land in soybeans is projected to exceed that in either corn or wheat by 15 or 20 million acres by 2010. This occurs even though soybean yields are projected to increase steadily at the rate established in the last three decades. Development of a soybean variety with significantly higher yield potential, while retaining other valuable characteristics, would make a significant contribution to restraining the rising demand for agricultural land and the attendent increases in economic and environmental costs.

3. On land with moderate to steep slopes conservation tillage greatly reduces erosion compared to conventional tillage. The expansion of cropland projected in this study implies that much land with high erosion potential will be shifted out of pasture and forest and into crops. The use of conservation tillage on this land would restrain the increase in erosion. Conservation tillage presently is not competitive with conventional tillage on poorly drained land, on land where weeds cannot be adequately controlled with herbicides, and in areas where the growing season is short. Research which would overcome these limitations to the spread of conservation tillage likely would have high pay-off in reduced erosion damages.

4. The spread of conservation tillage implies increased use of herbicides because the technology relies more on herbicides and less on cultivation than conventional tillage to control weeds. Present evidence does not indicate that the herbicides in wide use present serious threats to the environment. With a few exceptions they are not markedly toxic to animals when applied in generally used amounts, nor do they persist in the environment for long periods. Studies of their effects on soil microorganisms indicate that populations may be reduced immediately after application of herbicides but they recover and show no permanent impairment of important functions, e.g., fixing nitrogen.

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Not all possible ways in which herbicides may impact on soil organisms have been adequately investigated, however, nor have their effects on low trophic levels in aquatic environments. Moreover, the projected increase in herbicide use is large enough to cause concern if there is a

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possibility of threshhold effects of herbicides on the environment. The absence to date of evidence of strong adverse effects may be because these threshholds have not been passed.

The advantages of conservation tillage in controlling erosion are so strong that research to extend the technology should be pushed. To avoid unpleasant surprises from spread of the technology, however, research on the inadequately explored ways in which herbicides may adversely affect the environment should be included as an integral part of the research on conservation tillage.

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SECTION 1

PROJECTIONS OF PRODUCTION OF GRAINS, SOYBEANS AND COTTON IN THE UNITED STATES

INTRODUCTION

We are interested in these projections because the levels of production of these crops will determine in a major way the quantities of land, water, fertilizers, and pesticides that will be used in the United States. Alternative quantities of these resources, in turn, have varying economic and environmental consequences, the analysis of which is the main purpose of this study.

We deal with grains (wheat and feedgrains), soybeans and cotton for two reasons: (1) these crops consistently account for 70-75 percent of the land harvested in the United States and for high percentages of the fertilizers and pesticides applied; (2) if the growth of agricultural production in the United States over the next several decades puts substantial pressure on the demand for resources and on the environment, it will be because of the growth of production of these crops, particularly grains and soybeans. The growth in demand for all other agricultural commodities will respond primarily to growth in domestic population and income, and almost surely will be moderate. Under some conditions, however, export demand for grains, soybeans and cotton could increase enough to stimulate major increases in production of these crops.

PROJECTIONS TO 1985, 1990 AND 2010

Table 1-1 shows the projections as well as actual figures for 1977-79. The U.S. Department of Agriculture (USDA) projections were made by the National Interregional Agricultural Projections (NIRAP) model, and reflect a baseline situation. The principal assumptions underlying the baseline projections are that: (1) U.S. population will grow at the same rate from 1979 to 1985 as from 1970 to 1979 (.9 percent annually) and at a slightly slower rate (.8 percent annually) from 1985 to 1990; (2) real GNP will grow 3.0 percent per year from 1979 to 1985 and from 1985 to 1990, slightly less than in the 1970s (3.2 percent annually from 1969-71 to 1977-79); (3) export growth will be "moderate," i.e., less than in the 1970s.

We accept the USDA projections as a reasonable set of outcomes for 1985 and 1990. We think the projections of exports of feedgrains and cotton may be somewhat low and those for domestic use of feedgrains a bit high, but in

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TABLE 1-1

TABLE 1-1. U.S. PRODUCTION, EXPORT, AND DOMESTIC USE OF WHEAT, FEEDGRAINS AND COTTON, 1978/80 AND PROJECTIONS TO 1985, 1990 AND 2010 (millions metric tons)

					USDA		RFF: 2010			
							U.S. Share			
							Constant		Reduced	
	1978	1979	1980	Average 1978/80	1985	1990	(1)	(2)	(1)	(2)
Wheat										
Prod.	48.3	58.1	64.5	57.0	67.6	77.1	98	100	84	85
Export	32.5	37.4	41.5	37.1	42.4	50.4	70	72	56	57
Dom. Use	22.8	21.3	22.9	22.3	25.2	26.7	28	28	28	28
Feedgrains*										
Prod.	222.1	238.8	198.7	219.9	253.7	282.0	354	428	316	372
Export	60.2	71.4	74.3	68.6	81.0	97.1	167	241	129	185
Dom. Use	157.2	161.9	155.8	158.3	172.7	184.9	187	187	187	187
Soybeans										
Prod.	50.9	61.7	49.4	54.0	61.7	72.1	120	129	104	112
Export†	27.7	32.9	29.5	30.0	27.8	33.8	76	85	60	68
Dom. Use	23.5	23.7	24.0	23.7	33.9	38.3	44	44	44	44
Cotton										
Prod.	2.4	3.2	2.4	2.7	2.6	2.7	(share not calculated)			
Export	1.4	2.0	1.2	1.5	1.1	1.2	3.5-3.9			
Dom. Use	1.3	1.4	1.2	1.3	1.5	1.5				

Sources: 1978-1980 from USDA, Jan. 28, 1981 for wheat and feedgrains; USDA, Mar. 1981 for soybeans and cotton. 1985 and 1990, USDA projections provided by Leroy Quance, done in the summer of 1980. They represent a "baseline" situation, the assumptions of which are given in the text. The projections are preliminary and not official.

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TABLE 1-1 (Continued)

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TABLE 1-1. (Continued)

The RFF projections to 2010 are by Pierre Crosson. Constant U.S. shares means that the U.S. maintains the same percentage of world trade in the various commodities as in 1976/79; share reduced means a smaller percentage, as described in the text. The columns (1) assume that the Common Agricultural Policy of the European Community remains unchanged. The columns (2) assume that the policy is changed to permit more imports, as described in the text.

For 1978-80 the difference between production and the sum of exports and domestic use is the change in stocks. In the projections stock changes are assumed to be zero.

* Corn and sorghum for grain, oats and barley.

† The USDA projections are beans only. The 1978-80 figures and RFF projections to 2010 are beans plus soybean meal and oil exports converted to the bean equivalent.

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neither case are they implausible and the totals for 1985 agree closely with previous projections by RFF.[1]

There are no up-to-date USDA projections for 2010 so we made those shown in Table 1 independently. The projections for grains and soybeans were made in three steps: (1) project growth in world trade in each commodity; (2) project the U.S. percentage of trade; (3) project domestic use. The projections for cotton were derived from a USDA study (Collins et al., 1979) described below.

The detailed derivation of the projections is described in the appendix to this section. Here we discuss some general considerations relevant to evaluation of the projections.

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Sources of Error in Projections

The projections game is one many can, and do, play, and there is no firm basis for distinguishing the quality of the players. The range of equally plausible outcomes is wide because the range of plausible assumptions determining outcomes is wide. Over periods of twenty or thirty years, small differences in assumed rates of increase in population and per capita income, in income elasticities of demand, or in rates of growth of food production can yield large differences in projections of world trade, a key element in our, and other, projections.

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When projections depend upon extrapolation of trends--and all do to some extent--problems arise if the trend is not clear. Which periods should be selected to represent the trend if the data suggest the trend has shifted over time? Ordinarily, the most recent period should be used, but one frequently cannot be sure whether recent experience marks the beginning of a new trend or only a momentary departure from established trend. This is an especially difficult problem with trends in agricultural productions because the data may reflect variations in the weather. For example, a combination of unusually bad weather early in the period and unusually good weather later in the period can give a quite marked, and misleading, upward tilt to the trend in crop production.

Projections over periods as long as twenty or thirty years may also go wide of the mark because of the emergence of wholly unforeseen factors. Changes in dietary standards and habits could have a major impact on projections of food consumption and production. For example, our projections of feedgrain consumption in high-income countries assume that per capita

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[1] Crosson and Brubaker, May, 1979. Our projections in the referenced document were for 1985 and 2000 and were for grains and soybeans only. The ratios of our production projections for 1985 to those of the USDA in Table 1 were as follows: wheat, .984; feedgrains, 1.016; soybeans, 1.036. There was no trend in per capita domestic use of feedgrains between 1960 and 1979, so we projected this component of feedgrains in accordance with population growth. The USDA projections implicitly assume an increase in per capita domestic use of feedgrains.

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consumption of meat in those countries will rise toward U.S. levels, thus increasing per capita consumption of feedgrains and soybean meal. Trends in meat, feedgrain and soybean meal consumption in those countries indicate this is a plausible assumption, but concern about the health effects of high-meat diets may dampen those trends, leading to slower than projected growth of demand for feedgrains and soybean meal.

The emergence of new uses for crops may have the opposite effect. The prospect for long-term increase in the real price of fossil fuels has stimulated growing interest in alternative sources of energy. The use of crops to produce ethanol for blending with gasoline to form gasohol is an example. At present gasohol requires a subsidy to be competitive with gasoline, but continuing increases in the price of gasoline and progress in gasohol technology could eliminate this need. This is discussed further below.

The development and spread of new, and unanticipated, production technologies also may cause outcomes to differ widely from projections. Unexpected breakthroughs in research on photosynthetic efficiency or in development of new seed varieties conceivably could lead to faster than projected growth in food production and slower than projected growth in import demand in importing countries. Given the present state of knowledge of these processes, such occurrences are not likely to affect five-to-ten-year projections, but for periods of twenty-to-thirty years they cannot be ruled out. However, since there is no way of knowing when these developments may occur or what their production, consumption, and trade consequences may be, there is no point in trying to incorporate them in projections.

Policy changes also can cause projections to look foolish. The only policy change incorporated in our projections assumes more liberal trade and lower price policies in the European Community (EC) after the mid-1980s. We did this because of evidence of increasing concern in the EC about the high cost of present policies and the growing strength of consumer interests seeking lower real prices of food. We, of course, do not project that EC policies will change in the indicated direction. But, in our judgment, the likelihood of such change is sufficiently high and its implications for trade, particularly in feedgrains, sufficiently important that we ought to incorporate the change in our projections to 2010. Other policy changes, of course, are conceivable, although none that we have thought about are sufficiently likely, in our judgement, to warrant inclusion in the projections. We may be wrong, however. If so, then our projections will prove to be incorrect.

For all of these reasons we hold no brief that our projections are necessarily more plausible than others that have been or might be done, and we are confident that the projections will be wrong in ways we cannot now foresee. We believe, however, that our projections are internally consistent and reasonably in accord with present understanding about trends and policies bearing on U.S. production of grains, soybeans and cotton. That is all we claim for them.

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Comparison with Others

Table 1-2 provides a basis for comparing our projections with those by the USDA and by Martin Abel. The USDA projections are those for 1990 shown in Table 1. Abel's are for 2005 and are in a paper prepared for a conference held by RFF on the adequacy of agricultural land in the United States. For comparison with our projections we extrapolated those of the USDA and Abel assuming that the annual increments of production from 1977/79 to their target dates would continue to 2010. Thus the projections for 2010 labeled USDA and Abel in Table 1-2 are not their work but extrapolations by us of their projections.

TABLE 1-2. ALTERNATIVE PROJECTIONS OF U.S. PRODUCTION OF WHEAT, FEEDGRAINS AND SOYBEANS (millions metric tons)

				2010 Extrapolations of		
	1977/79	USDA 1990	Abel 2005	USDA	Abel	RFF
Wheat	54.2	77.1	83	115	88	98
Feedgrains	218.8	282.0	405-435	387	439-475	354
Soybeans	53.5	72.1	64-76	103	66-80	120

January 28, 1981

Sources: 1977/79 - USDA, January 28, 1981
USDA - from Table 1, this report
Abel - paper given at an RFF conference on the adequacy of agricultural land (see Abel in references)
RFF - from Table 1, this report. See appendix to this section for details on derivation.

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Note: Abel projects oilseed production, not soybeans only. Typically, soybeans account for 85-90 percent of oilseed production in the United States. We have assumed that soybeans are 85 percent of Abel's projection for 2005.

The extrapolated USDA projections of feedgrains and soybeans are much closer to ours than are Abel's. Abel assumes a major increase in production of corn to produce ethanol for combination with gasoline to produce gasohol. He also anticipates a significant increase in corn production for use as a sweetener. Both uses of corn yield a high protein residue which competes directly with soybeans as a feed supplement. Abel's assumptions about the growth of demand for corn for production of ethanol and sweetener thus accounts for much of the difference between his extrapolated projections and ours for feedgrains and soybeans in 2010. The extrapolated USDA projections for feedgrains and soybeans differ from ours in the same way as Abel's, but the amount of the difference is much less. The USDA projections also assume

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increased production of corn for ethanol production, but evidently on a smaller scale than Abel assumes.

Our projections make no special allowance for use of corn to produce ethanol or sweeteners. In the 1980s ethanol production based on corn almost surely will expand substantially. Whether this will constitute a permanently higher demand for corn, however, is not clear. At a meeting of the Bio-Energy World Congress and Exposition, held in Atlanta in April, 1980, most speakers agreed that wood eventually will prove more economical than grain as a source of biomass for energy production (Science, page 1018). Abel, in discussion with one of the author's, agrees that there is great uncertainty about the long-run course of ethanol production, and that by 2010 wood, or more likely coal, may well replace corn as the main nontraditional feedstock for production of liquid fuel. Abel believes, however, that the corn based production capacity built in the 1980s will be maintained. We are not persuaded on this latter point. By the spring of 1981 much of the ardor for gasohol evident in mid-1980 appeared to have cooled. Informal reports received by the authors indicated that some of the plant expansion plans announced in 1980 were being cut back or deferred. The Reagan administration was taking a more cold-eyed look than its predecessor at the subsidies in the gasohol program. All of this, combined with the prospect that by the 1990s alternative feedstocks will prove more economical than grain, suggests to us that by 2010 the demand for grain for ethanol will be insignificant. This is the justification for our decision not to make special allowance for corn-based production of ethanol in our projections of feedgrain production. It follows that we would not make a corresponding adjustment in our projections of soybean production.

With allowance for the difference with respect to treatment of the role of corn in ethanol production we believe that Table 2 indicates that our projections are generally consistent with those of the USDA and Abel. The differences in the total tonnage of grains and soybeans are small for thirty year projections. This, of course, does not mean that we are right, but it does suggest that our thinking about the long-run prospects for U.S. production of grains and soybeans is not grossly different from that of others who have labored in this field. In work of such great uncertainty only gross differences should be taken as significant.[2]

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[2] Since this was written the National Agricultural Lands Study (NALS, 1981) published a set of USDA projections for 2000 which imply substantially higher rates of growth in production and exports than any of those shown in Table 1. Specifically, the NALS median projections (a range is given) are 2.7 percent annually for total production from 1980 to 2000 and 5.5 percent annually for total exports. The RFF 2010 projections (Column 1, U.S. share constant) in Table 1 imply the following annual growth rates from 1980:

	Production	Exports
	(percents)	
Wheat	1.4	1.8
Feedgrains	1.9	2.7
Soybeans	3.0	3.2
Cotton	1.5	not projected

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The RFF projections in Table 1-1 labeled "U.S. Share Constant" are based on no explicit assumptions about crop prices except that their influence on the growth of domestic and foreign demand will be small relative to the influence of world population and income growth. In fact, we think real prices received by American farmers for grains, soybeans, and cotton are more likely to rise over the next several decades than they are to remain at 1979 levels. The reason is our expectation that real prices of key inputs--energy, fertilizer, water and land--are likely to increase more than productivity. The basis for these expectations is given in subsequent chapters.

If U.S. production costs rise more than our constant share projections implicitly assume, U.S. shares of world trade in grains, soybeans, and cotton could decline. To allow for this possibility we prepared projections of U.S. production, exports, and domestic use assuming a diminished share of world trade. These are labled "U.S. Share Reduced" in Table 1-1. Obviously we think the likelihood of the United States losing ground in world trade is sufficiently high to warrant presentation of the alternative projections. However, in analyzing the demand by U.S. farmers for resources and the environmental impacts of production we focus only on the constant share projections assuming no change in the EC's Common Agricultural Policy. This set of projections in our judgment is the most probable set. It would have been interesting to explore the resource and environmental implications of the alternative projections, but our resources did not permit this.

use

The USDA model which generated the projections for 1985 and 1990 shown in Table 1-1 also generates prices for wheat, feedgrains and soybeans. These are shown in Table 1-3 along with 1979 prices. The model indicates a decline in real prices of wheat and increases for corn, sorghum, oats, barley, and soybeans. Weighting the four feedgrains by their shares of total feedgrain production of 1979 indicates an increase in average real prices of feedgrains of about 22 percent from 1979 to 1985 and about 31 percent from 1979 to 1990. We have not explored in detail why the NIRAP model shows rising real prices for feedgrains and soybeans, but the general reason is rising real prices of key inputs not sufficiently offset by increases in productivity.

(Footnote 2 continued)

Demand is projected to grow more rapidly for grains and soybeans than for other components of agricultural production. Consequently the differences between the RFF projections of those commodities and the projections of them embodied (but not shown separately) in the NALS projections are greater than the above percentages indicate. The NALS projections assume constant relative prices and ours allow for some real increase in prices, as noted below. Nonetheless, it is likely that the constant price equivalents of the RFF projections would be less than the NALS projections. By that comparison, therefore, the RFF projections probably are conservative.

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TABLE 1-3. CROP PRICES RECEIVED BY FARMERS, DOLLARS OF 1979 ($/bu.)

	1979	1985	1990
Wheat	3.82	3.09	3.33
Corn	2.41	3.01	3.22
Grain sorghum	2.33	2.70	2.89
Oats	1.36	1.38	1.47
Barley	2.31	2.32	2.47
Soybeans	6.19	7.36	7.85

Sources: 1979, USDA, June 1980.
The data for 1985 and 1990, from print-out of projections of the USDA's NIRAP model, provided by Leroy Quance (see note to Table 1-1). The NIRAP model generates projections of nominal crop prices and of the implicit price deflator for GNP. The latter was used to convert nominal prices to "real" prices, i.e., prices expressed in 1979 dollars. The NIRAP model does not generate prices for cotton.

Martin Abel points out that wheat is not likely to sell for less than its value as feed. In this case the projected prices of corn are too low or those for wheat are too low.

Martin Abel's projections, shown in Table 1-2, explicitly assume no change in real crop prices between 1980 and 2005. If real prices in fact change, as the NIRAP projections indicate and we think likely, Abel's projections would be modified accordingly. He asserts (Abel, p. 1) as follows:

> Our projections for the U.S. and the world would have to be modified if alternative real price assumptions were used, and the modifications would depend upon whether the price change was due to factors affecting either demand or supply.

In summary, the projections we use to examine the resource and environmental implications of increased agricultural production in the United States do not exclude the possibility of changes in real crop prices. But they do assume that the effect on demand of any such changes will be small relative to the effects of world population and income growth, and that, in particular, any such changes will not significantly alter the U.S. share of world trade in wheat, feedgrains, and oilmeal.

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SECTION 2

FACTORS AFFECTING FARMERS' CHOICES AMONG TECHNOLOGIES: PRICES OF INPUTS

INTRODUCTION

Meeting our projected levels of production of grains, soybeans and cotton will increase the demand by American farmers for resources. The amount of the increase for each type of resource depends upon the kinds of technologies farmers choose. We assume that in making these choices, farmers seek to maximize their incomes, and that the choices are conditioned fundamentally by the prices and productivities of alternative technologies. In this section we consider prices of certain key inputs. Productivity is considered in the next section. Farmers' choices also are affected by public policies. In most cases these will be reflected in prices of technologies. In some, however, it will not, as when the Environmental Protection Agency (EPA) bans an insecticide. In these cases policy is a separate factor influencing farmers' choices, and we treat it as such where appropriate.

TYPES OF TECHNOLOGY

Technologies frequently are labeled according to the intensity of use of some particular input relative to other inputs. For example, a technology using much labor relative to capital is called labor-intensive, or labor-using, to distinguish it from another technology in which the ratio of labor to capital is lower. Similarly, technological innovations may be described as "saving" or "using" with respect to some particular input, depending upon whether the proportion of that input to other inputs is less or more in the new technology than in the one it replaces.

We find it useful to distinguish agricultural technologies as land-using or land-saving, according to whether the ratio of land to other inputs is high or low. The implication is that technologies should be thought of as lying along a spectrum ranging from very land-using (high ratios of land to other inputs) to very land-saving (low ratios of land to other inputs). A given technology will be land-saving relative to some technologies and land-using relative to others.

inputs

The distinction between the two kinds of technology lacks precision. It is useful, however, for analysis of the land use and environmental implications of expanding agricultural production. To meet a given increase in production, land-using technologies imply slower growth of yields, hence

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greater demand for land than land-saving technologies. The distinction is useful also because the environmental implications of the two kinds of technology are different. With land-using technologies, problems of erosion typically will be more important relative to problems of agricultural chemicals than with land-saving technologies.

As with any analytical device, the distinction between land-using and land-saving technologies will not catch all the nuances of reality. For example, American farmers who expand crop production with land-using technologies typically will also apply fertilizers and pesticides to the land. Consequently, the land-using mode of expansion may entail environmental costs of fertilizer and pesticide pollution as well as costs of erosion. In the same sense, farmers who adopt the land-saving mode may nonetheless cause increased erosion by abandoning erosion control practices, such as strip-cropping, in an effort to maximize production per unit of land. Since either mode of expansion may entail environmental costs associated primarily with the other, the two categories of technology should be regarded as polar cases, the actual technologies employed being chosen from the spectrum in between.

CHOICES AMONG TECHNOLOGY: A HISTORICAL PERSPECTIVE

Table 2-1 indicates that between 1951-1955 and 1972, the trend of American farmers' choices among technologies was weighted toward the land-saving end of the spectrum. In this period the ratio of all purchased inputs (not including labor) to cropland used for crops rose 61 percent. The increase in the ratio of fertilizer to cropland was particularly high--266 percent.

TABLE 2-1. RATIOS OF INPUTS TO CROPLAND USED FOR CROPS IN U.S. AGRICULTURE (1967=100)

	Fertilizer*	All Purchased Inputs
1951-55	35	67
1956-60	46	77
1961-65	70	92
1966-70	108	102
1971	123	105
1972	128	108
1973	123	105
1974	129	102
1975	115	99
1976	136	106
1977	141	109
1978	134	116
1979	140	119

Source: USDA, February 1981.
*Per acre of cropland harvested.

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This trend toward land-saving technologies from the beginning of the 1950s to 1972 was consistent with the behavior of relative input prices in this period. Table 2-2 supports this. The prices of all purchased inputs and of fertilizers fell relative to the price of land, measuring the latter by the per acre value of farmland and buildings ($Land_A$ in Table 2-2). The prices of purchased inputs and of fertilizer rose from 1951/55 to 1956/60 relative to the capitalized value of land rents ($Land_B$) but fell thereafter to the early 1970s. Relative to the $Land_A$ price purchased input prices and prices of fertilizer continued to fall after the early 1970s, but at a much slower annual rate than in the two previous decades. By contrast, purchased input prices and fertilizer prices rose relative to the capitalized value of land rents after 1974, reversing the previous trend. The behavior of input prices relative to land prices since the early 1970s thus is consistent with the slower shift to land-saving technologies in that period, the price effects being particularly marked when price is measured by the capitalized value of land rents.

TABLE 2-2. RATIOS OF INPUT PRICES TO PRICES OF LAND AND PRICES OF FERTILIZER
(1967 = 100)

	Relative to Land				Relative to Fertilizer
	$Land_A$		$Land_B$		
	All purchased inputs	Fertilizer	All purchased inputs	Fertilizer	All purchased inputs
1951-55	180	207	181	203	89
1956-60	147	167	294	322	91
1961-65	122	133	223	237	94
1966-70	95	87	159	145	110
1971	91	73	177	143	124
1972	89	69	190	148	128
1973	91	64	103	72	143
1974	85	85	57	57	100
1975	83	98	71	85	84
1976	76	73	94	90	104
1977	69	63	129	117	110
1978	68	56	163	136	120
1979	68	54	na	na	127

Sources: $Land_A$, all purchased inputs and fertilizer from USDA, Agricultural Statistics, 1972 and 1979. $Land_B$ from Castle and Hoch, 1980. $Land_A$ is an index of the value per acre of farmland and buildings. $Land_B$ is the capitalized value of annual net rents earned by farmland, calculated by Castle and Hoch from USDA data.

The implications for farmers' choices among technologies of the price ratios in Table 2-2 are not as unambiguous as they may seem. The reason is that land prices are themselves affected by farmers' choices but prices of the other inputs are not, at least not in the long run. Prices of fertilizer and other farm inputs are determined primarily by the costs of producing these inputs, or in any case by factors other than farmers' demand for them.[1]

This is not true of land prices, however. The greater part of the demand for farm land comes from farmers.[2] There is interdependence, therefore, between the price of land and farmers' choices between land-using and land-saving technologies. This is not true (or not true to nearly the same extent) of nonland inputs, for which farmers are price takers.

The implication is that movements in the price of farm land reflect movements in the demand and supply curves of land relative to one another. For this reason our analysis of the role of land in farmers' future choices between land-saving and land-using technologies focuses on factors affecting the demand curve for land and the resulting supply response. Drawing on the analysis in this and the following section of the future behavior of the prices and productivity of non-land inputs we project the demand for land needed to produce our projected amounts of crop output. In a subsequent section we examine the supply response of cropland and make a judgment about the effect on land price of the supply-demand interaction.

In this section we focus on the prices of fertilizer and energy, and on the cost and availability of water for irrigation, because these are the principal land-saving inputs.

PRICES OF INPUTS

Energy

American farmers use large amounts of energy to drive tractors and other farm machinery, to pump irrigation water, to dry crops, and in the form of nitrogen fertilizer and pesticides. With respect to farmers' choices among land-using and land-saving technologies, the two most important uses of energy are for producing nitrogen fertilizer and for pumping irrigation water.[3]

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[1] This probably is less true of fertilizer prices than of other inputs. The United States accounts for 20-25 percent of world consumption of nitrogen and potash fertilizers, and for about 20 percent of consumption of phosphorus fertilizers. These amounts suggest that short-term shifts in U.S. demand likely would affect fertilizer prices.

[2] Duncan (June 1977) indicates that in 1975, 63 percent of farm real estate transfers in the United States were to farmers, about the same as in the previous three decades.

[3] USDA (1976) shows that in 1975 fertilizer accounted for 30.8 percent of energy used in farm operations in the United States and irrigation for 12.9 percent. Field operations took 25.9 percent, presumably for tractors and other farm machinery.

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According to Dvoskin and Heady, about 30 cubic feet of natural gas are used on average to produce one pound of nitrogen fertilizer. In the winter of 1979/80 farmers in the High Plains were paying about $2.00 per thousand cubic feet (mcf) for natural gas.[4] At that time, the nitrogen content of anhydrous ammonia, the most widely used form of nitrogen fertilizer, was valued at about $.13 per pound.[5] At these prices, therefore, natural gas constituted a little over 45 percent of the price of anhydrous ammonia. These numbers are only illustrative, but they make the point that the cost of natural gas has an important influence on the price of nitrogen fertilizer.

Table 2-3 shows an index of the real prices paid by farmers for fuel and energy from 1965 to 1979. This price series dates only from 1965, but there is little doubt that real energy prices paid by farmers declined more or less steadily from the beginning of the 1950s to the early 1970s.[6] After 1973, however, these prices rose sharply and in 1979 were 46 percent above 1973.

The decline in real energy prices from the 1950s to the early 1970s contributed importantly to the decline in the real price of fertilizers in this period (noted above) and to the spread of irrigation (detailed later in this section). Should real energy prices continue to rise, the trends in prices of nitrogen fertilizer and of irrigation are likely to be less favorable to the adoption of land-saving technologies in the future than they were in the two decades ending in the early 1970s.

TABLE 2-3 INDEX OF REAL PRICES PAID BY FARMERS FOR FUEL AND ENERGY IN THE UNITED STATES (1967 = 100)

Year	Index	Year	Index
1965	104	1972	86
1966	101	1973	87
1967	100	1974	108
1968	97	1975	110
1969	93	1976	110
1970	89	1977	111
1971	88	1978	108
		1979	127

Sources: USDA Agricultural Statistics, 1980. The "real" price is the index of nominal prices divided by the Consumer Price Index. The series for fuel and energy prices paid by farmers begins in 1965.

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[4] Information obtained from officials in Texas, Oklahoma, Kansas, and Nebraska in January 1980.

[5] The average price of anhydrous ammonia in the winter of 1979/80 was about $.11 (USDA, May 30, 1980, p. 44). Nitrogen is 82 percent of anhydrous ammonia so a pound of N in anhydrous ammonia cost $.13.

[6] In real terms the electricity, gas, fuel oil, and gasoline components of the Consumer Price Index (CPI) were all lower in the early 1970s than in 1950. Energy prices paid by farmers must have moved in a similar fashion.

There is a consensus that the real price of energy will continue to rise. This is evident from a major study done at Resources for the Future of energy alternatives for the United States (Schurr, et al.). The study includes a review of studies done by others of energy prospects for the United States to the end of the century. All of the studies assume that real energy prices will rise from 1975 to 2000. There are differences among the projections in the amount of price increase, but all agree that real natural gas prices will rise most and coal and electricity prices least. The average rate of increase for all energy sources is roughly 2 percent per year from 1975 to 2000.

It should be noted that none of these projections of real energy prices emerges directly from analyses of trends in world energy supply and demand. Instead they are based on past trends and on informed judgments about the effect on prices of trends in technology, of known reserves and new discoveries, OPEC policies, and so on. The authors of each of the studies obviously believe that the price projections are consistent with projections of energy demand and supply, but they are not derived from the analysis of demand and supply. We make this point not to cast stones at the price projections--we would do them in the same way--but to emphasize that the projections are based on _ad hoc_ judgments rather than on systematic analysis of underlying relationships and tested hypotheses about the determinants of energy prices. The large role of judgment relative to analysis means that faith (or lack of it) weighs more heavily in acceptance or rejection of the projections than it would if the roles of judgment and analysis were reversed. We have no basis for questioning the judgments, but we recognize that we accordingly accept the price projections largely on faith.

We assume, therefore, that real energy prices paid by American farmers (directly or indirectly) will rise steadily to the end of the century and beyond at a rate of some 2 percent annually, that prices of natural gas will increase substantially faster than 2 percent (without specifying how much faster), that electricity prices will rise by less than 2 percent annually, and that prices of other energy sources will rise at rates somewhere between those for electricity and natural gas.

Fertilizers[7]

While energy is an important component in the prices of fertilizers, particularly nitrogen, other factors also are important. It now is generally agreed that the run-up in fertilizer prices in 1974 and 1975 resulted more from rising pressure of demand on supply than from the increase in energy prices in those years. Similarly, the decline in fertilizer prices after 1975 occurred despite continued increases in energy prices. Thus, while our

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[7] This section is based primarily on USDA (Dec. 1978b) and on discussions with people at USDA, the World Bank, and the International Fertilizer Development Center at Muscle Shoals. The USDA does much work on projections of quantities of fertilizers supplied and demanded, but little or nothing on prices, at least for publication. Of the three institutions contacted, only the World Bank currently projects world fertilizer prices, and these are not published.

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projections of rising real prices of energy imply upward pressure on fertilizer prices, particularly for nitrogen, other factors may offset this pressure. Projections of fertilizer prices must take these other factors into account as well as trends in energy prices.

Table 2-4 shows measures of the "real" price of fertilizers in the United States. Prices are shown relative to the cost-of-living index and relative to the price of corn. The relation to the price of corn probably carries more weight in farmers' decisions about the use of fertilizer. The significant point in the table is that since the mid-1970s the real price of fertilizer, whether measured against the CPI or the price of corn, has been sharply higher than in 1970. Projections in a study of demand and supply in the world fertilizer industry indicate that the growth of world capacity to produce nitrogen fertilizers would exceed the growth of consumption from 1978 to 1985, but that for phosphate and potash fertilizers, capacity would increase less than consumption (Harris and Harre). The ratios of consumption to capacity in 1978 and 1985 are as follows:

Ratios of World Fertilizer Consumption to Capacity[8]

	1978	1985
Nitrogen	.97	.93
Phosphate	.88	.94
Potash	.92	1.04

These ratios suggest that, other things the same, nitrogen prices would be about the same to slightly weaker in 1985 compared to 1978, but that prices of phosphate and potash fertilizers would be higher. "Other things," however, are not likely to be the same. The anticipated increase in the real price of natural gas would tend to increase the cost of production of nitrogen fertilizers, quite apart from trends in consumption and capacity in that industry. Studies done at the World Bank conclude that rising costs of construction of new plants also likely will put upward pressure on real prices of nitrogen fertilizer, and also on prices of phosphates and potash. According to these studies, real prices of the fertilizers in 1985 could be 15 to 20 percent above the levels of 1978. While projections beyond 1985 are not available, we assume the increase in energy prices will put steady upward pressure on fertilizer prices, particularly for nitrogen, and that these prices will rise in real terms to the end of the century and beyond.

Water

Irrigation is a highly land-saving technology, substituting a controlled water supply and other inputs for land. However, little of the water used for irrigation in the United States is traded through markets. Most of it either is pumped from aquifers or rivers by the farmers who use it or is provided by publicly funded surface water systems at highly subsidized prices. Hence prices paid by farmers for irrigation water, where they exist at all, bear little relationship to the true scarcity value of the resource. However, where farmers are free to sell their rights to water to nonagricultural users the water has an opportunity cost to the farmer, the amount depending upon the strength of the nonagricultural demands. Hence, trends in those demands

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[9] Harris and Harre, p. 23-27.

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TABLE 2-4. INDEXES OF REAL PRICES OF FERTILIZERS IN THE UNITED STATES (1970 = 100)

	Nitrogen*		All Fertilizer	
	Relative to CPI	Relative to price of corn	Relative to CPI	Relative to price of corn
1970	100	100	100	100
1971	102	131	99	127
1972	100	94	99	91
1973	103	61	101	61
1974	193	108	149	84
1975	256	186	178	129
1976	174	158	143	130
1977	155	160	132	135
1978	133	142	122	121
1979	134	148	119	122

Source: Nitrogen prices are from USDA (Dec. 1978b and June 1980); 1977, 1978 and 1979 are averages of prices of May 15 and October 15 in each year; consumer price index, corn prices and index of all fertilizer prices from USDA, Agricultural Statistics 1980.

*Anhydrous ammonia, which accounts for almost 60 percent of nitrogen fertilizer production in the United States.

are an indicator of trends in the "price" of water used for irrigation. The other principal indicator is the cost of pumping groundwater. Accordingly, in this discussion we focus on the increasing competititon for water for agricultural uses and on the costs of pumping groundwater.

Table 2-5 gives information about irrigation in the United States in 1977, and Table 2-6 shows irrigated and rainfed land, by region, in corn, soybeans, wheat, and cotton in 1950 and 1977. We deal first with western irrigation and subsequently with irrigation in the East.

Western Irrigation--

Table 2-6 is of particular interest because of the substantial increase it shows between 1950 and 1977 in irrigated acreage in the West of crops of interest to this study.[9] This increase was stimulated by easy access to low-cost water. In the West water has commonly been treated as a free good to

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[9] The West means the seventeen westernmost states. This account of the role of irrigation in the West draws heavily from Frederick. Irrigated production of soybeans is trivial in the West.

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TABLE 2-5. 1977 IRRIGATED AND DRYLAND AGRICULTURAL LAND USE BY FARM PRODUCTION REGION (millions of acres)

Farm Production	Irrigation			Dryland			Total		
Region	Cropland	Pasture	Total	Cropland	Pasture	Total	Cropland	Pasture	Total
Northern Plains	10.6	0.1	10.7	83.9	9.4	93.3	94.6	9.5	104.1
Southern Plains	8.6	0.4	9.0	33.6	27.1	60.7	42.2	27.5	69.7
Mountain	15.2	2.0	17.2	27.1	5.5	32.6	42.2	7.4	49.6
Pacific	11.9	1.4	13.3	11.2	2.8	14.0	23.2	4.1	27.3
17 Western States	46.4	3.9	50.2	155.8	44.7	200.5	202.2	48.5	250.7
Northeast	0.4	0	0.4	16.5	5.8	22.3	16.9	5.8	22.7
Appalachian	0.4	0	0.4	20.4	18.5	38.9	20.8	18.5	39.3
Cornbelt	1.1	0	1.1	88.8	25.2	114.0	89.9	25.2	115.1
Lake States	1.0	0	1.0	43.2	6.9	50.1	44.1	6.9	51.0
Southeast	2.4	1.0	3.4	15.1	13.1	28.2	17.5	14.1	31.6
Delta States	4.0	0.1	4.1	17.2	12.6	29.8	21.2	12.7	33.9
31 Eastern States	9.3	1.1	10.4	201.2	82.1	283.3	210.4	83.2	293.6
National Total	55.7	5.0	60.7	357.2	127.8	486.1	412.9	132.7	546.9

Source: Tables 3a and 4a, USDA, February 1980.

Note: Minor differences in totals are due to rounding.

TABLE 2-6. IRRIGATED AND DRYLAND ACREAGE OF CORN, SORGHUM, WHEAT, AND COTTON FOR 1950 AND 1977
(1000 harvested acres)

		1950	1977
Corn:*	Irrigated West	46	8,838
	Dryland West	16,933	4,572
	East	55,486	56,596
	U.S. Total	72,465	70,006
Sorghum:*	Irrigated West	894	1,847
	Dryland West	9,435	10,774
	East	13	1,444
	U.S. Total	10,342	14,065
Wheat:	Irrigated West	911	3,899
	Dryland West	48,555	49,387
	East	12,141	12,930
	U.S. Total	61,607	66,216
Cotton:	Irrigated West	1,563	3,868
	Dryland West	6,949	5,212
	East	9,331	4,199
	U.S. Total	17,843	13,279

Sources: The total acreage estimates for the West and United States in 1977 are from USDA, Agricultural Statistics 1978. The 1977 irrigated and dryland acreages are based on data from the Agricultural Census of 1974, adjusted by information from the National Resources Inventory (NRI). Details are in Frederick, notes 4 and 5. The 1950 estimates also are from Frederick.

*For grain only.

anyone able to transport it to the place of use. In addition, western irrigation benefitted from substantial subsidies from federally developed irrigation projects, which now water about one-fifth of the land irrigated in the region. Cheap energy also spurred the growth of irrigation, especially from groundwater.

The days of cheap water in the West appear to be over. Current demands on western rivers commonly exceed available supplies, and groundwater tables

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are declining in some important areas. In addition, demands for nonagricultural uses of water are rising rapidly. The value of water in these uses typically is much higher than in agriculture, making it difficult for farmers to compete on economic terms with nonfarm demanders of water. For example, water costs of $100 per acre-foot are insignificant to the costs of mining or processing western coal, but costs of even half this much are prohibitive to most farmers. In areas of the West where nonagricultural demands for water have risen sharply, some farmers already have found it profitable to sell their water rights and many others are likely to do the same unless legal constraints prohibit them. Because the amount of water used in western agriculture is so much greater than that in nonagricultural uses, large percentage increases in the latter could be met by relatively small diversions from agriculture. Hence, no large general reduction in the amounts of water used for irrigation in the West is expected. The shifts out of irrigation may be significant in some local areas, however, and the general effect is likely to be slower growth in irrigation than otherwise would occur.

Groundwater emerged as an important source of water for irrigation in the West in the 1930s. In the 1970s the expansion of irrigation was based largely on groundwater, and this now is the principal source of supply in many areas of the West. Pumping commonly exceeds aquifer recharge, the highest rates of such "mining" being in the High Plains of Texas, Oklahoma, New Mexico, Colorado, and Kansas, and in Arizona. These areas account for 20 percent of the irrigated land in the West.

Mining does not threaten to exhaust groundwater supplies in the foreseeable future, but it lowers water tables, thus increasing costs of pumping. Pumping costs promise to rise also because of increasing energy costs. Tables 2-7 and 2-8 show, respectively, the areas irrigated with pumped water by type of energy in 1974, and energy requirements for on-farm pumping of water. The tables refer to the whole United States, but most water pumped for irrigation is used in the West. Whether in terms of area irrigated or

TABLE 2-7. ACRES IRRIGATED WITH ON-FARM PUMPED WATER
IN THE UNITED STATES BY TYPE OF ENERGY, 1974

	(1,000 Acres)			
Energy	Groundwater	Surface water	Total	Percent of all energy types
Electricity	11,721	3,900	15,621	44.5
Diesel	2,693	1,242	3,935	11.2
Gasoline	1,025	523	1,548	4.4
Natural gas	9,687	948	10,635	30.4
LPG	2,585	753	3,338	9.5
Total	27,711	7,366	35,037	100.0

Source: Sloggett (1977), p. 7.

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TABLE 2-8 ENERGY REQUIREMENTS FOR ON-FARM PUMPING OF IRRIGATION WATER IN UNITED STATES BY TYPE OF ENERGY, 1974

Energy	(Billion BTU) Ground-Water	Surface Water	Total	Percent of all energy types
Electricity	48,580	17,028	65,607	25.2
Diesel	22,342	2,471	24,813	9.5
Gasoline	7,379	1,451	8,830	3.4
Natural Gas	135,098	3,857	138,955	53.3
LPG	20,496	1,967	22,463	8.6
Total	233,895	26,773	260,668	100.0

Source: Sloggett (1977), p. 8.

amounts of energy used, electricity and natural gas are by far the two most important forms of energy used for irrigation.

Energy costs are an important component of costs of producing irrigated grains. Corn production in the Southwest illustrates this. Most corn produced in that area is irrigated. In 1978 costs of fuel and lubrication were 20 percent of variable costs of production, and 12 percent of total nonland costs (U.S. Senate). Among variable costs only fertilizer exceeded fuel and lubrication, and that by a small margin. In Texas, which accounted for 80 percent of the corn produced in the Southwest in 1978, natural gas was the energy source for 72 percent of all irrigated land (not just corn land). Electricity provided 22 percent of the energy, with diesel fuel, gasoline, and LPG making up the rest.[10] Natural gas was relatively much more important in irrigation in Texas than in the country as a whole (see Table 2-7).

Our discussion of trends in energy prices indicated a consensus that real prices will increase by some 2 percent annually between 1975 and 2000, with natural gas prices rising substantially more than this, electricity prices somewhat less, and prices of other energy sources somewhere between those of electricity and natural gas. In the studies referred to in our discussion, the projections of increases in natural gas prices varied between 5.0 percent and 9.6 percent annually. Given the importance of natural gas in on-farm requirements for pumping, these projections imply that the real price of energy used for irrigation would rise more than 2 percent annually.

Table 2-9 gives estimates of the effects of higher energy prices and declining water tables on costs of pumping one acre foot of water in the West.

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[10] Sloggett (1977). In the calculation of costs of corn production, the Southwest consists of Texas and California.

Thirty-three million acres of land in the West are irrigated by onfarm-pumped water, and somewhat more than half of this is land in Texas, Oklahoma, Kansas, and Nebraska irrigated with groundwater (Sloggett 1979). The feet of lift to water that land are 100 in Nebraska, 180 in Kansas, and 200 in Texas and Oklahoma. As noted above, aquifers in those states are being mined, so water tables are declining over time.

Table 2-9 suggests that the combination of rising energy costs and declining water tables would lead to sharply higher costs of pumping by 2000. With no decline in the table pumping costs in 2000 would be double the 1980 level, and a 100-foot decline in the table, combined with rising energy prices, would increase costs three to four times. These numbers probably underestimate the increase in average pumping costs (given the assumed increase in energy prices), because natural gas, the cheapest present source of energy, is likely to decline as a percentage of total energy supply. A farmer who found it necessary to shift from natural gas to electricity and whose pumping depth increased from 100 to 200 feet would find his pumping costs rising from $4.56 per acre-foot in 1980 to $35.52 in 2000, an increase of almost 700 percent (table 2-9).

Since energy costs are only a part of total costs, the profitability of pump irrigation is more sensitive to changes in crop prices than to changes in energy costs. The USDA's NIRAP model projects a decline in real prices of wheat between 1979 and 1990 (Table 1-3, previous section). Should this occur an increase in pumping costs of the sort depicted in Table 2-9 would surely discourage, if not prohibit, the expansion of irrigated wheat production based on groundwater. Indeed, the present 3.9 million acres of western wheat irrigated by groundwater might well be forced out of production.

The NIRAP model projects an increase of one-third in the real price of corn from 1979 to 1990. If energy costs are 12 percent of total nonland costs of irrigated corn production, as indicated above, then a one-third increase in the price of corn would offset an almost fourfold increase in the price of energy, assuming that all other costs remained the same. However, if real energy costs double, as assumed here, other costs are not likely to remain the same. We already have noted that rising real energy prices are one of the principal reasons for projecting higher prices of nitrogen fertilizer, also a major component in production costs of corn. In addition, as noted above, the combination of falling water tables and a shift from lower-cost natural gas to other higher-cost sources of energy for pumping could increase average pumping costs sevenfold or even more.

We conclude that over the next several decades increasing competition for water for nonagricultural uses and rising real energy prices will make irrigation water in the West more expensive in real terms, without attempting to project how much the increase may be.

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TABLE 2-9. ENERGY COSTS TO PUMP 1 ACRE-FOOT OF WATER FROM DIFFERENT DEPTHS WITH ALTERNATIVE FUELS AND FUEL PRICES* *(1977 $)*

	Pump Lift (Ft.O	Energy Costs Under Alternative Fuel Prices 1970	1980	2000
Natural gas	100	1.13	4.56	9.12
	200	2.30	9.29	18.58
	300	3.43	13.86	27.72
Electricity	100	7.52	8.88	17.76
	200	15.03	17.76	35.52
	300	22.55	26.64	53.28
LPG	100	7.32	12.60	25.20
	200	14.65	25.20	50.40
	300	21.98	37.80	75.59
Diesel	100	5.24	14.96	29.92
	200	10.59	30.00	60.00
	300	15.74	44.96	89.92

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Source: Table 10 from Frederick.

*The technical assumptions such as the amount of fuel and the pressure required to lift an acre-foot of water are based on information in Sloggett (1979). Other assumptions include a 60 percent pumping efficiency and fuel costs in 1977 constant dollars as follows: natural gas ($/mcf) .39 in 1970, 1.58 in 1980, and 3.15 in 2000; electricity ($kWh), 0.033 in 1980, 0.039 in 1980, and 0.078 in 2000; LPG ($/gal.) .25 in 1970, .43 in 1980, and .86 in 2000; diesel ($/gal.) .28 in 1970, .80 in 1980, and 1.60 in 2000. The 1970 prices for LPG and diesel are national averages obtained from U.S. Department of Agriculture, June 1977. The 1970 price for electricity is from USDA, October 1977. There was a wide range in the natural gas prices paid by High Plains irrigators in 1970. The table assumes a price of 25¢/mcf in 1970 dollars. The 1980 prices reflect average prices paid by farmers in Nebraska, Kansas, Oklahoma, and Texas in January 1980. The prices were obtained through phone conversations with several officials in those states. Based on a conclusion of a recent major energy study (Landsberg et al., p. 71), it is assumed that real fuel prices will double by the year 2000.

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Eastern Irrigation--[11]

Table 2-5 indicates that in 1977 one-sixth of the nation's irrigated land was in the thirty-one eastern states, 75 percent of that in the Southeast (Alabama, Florida, Georgia and South Carolina) and the Mississippi Delta (Arkansas, Louisiana and Mississippi). The figures in Table 2-5 understate the amount of irrigated land in the Delta because most of the 776,000 acres of irrigated land in Missouri (a Cornbelt state) are in the southeast corner of the state, a region counted as part of the Delta for soil classification purposes, but not for statistical purposes.

The percentage increase in eastern irrigation exceeded that in the West from 1967 to 1977, with most of the increase in the Southeast, Delta (counting Missouri as part of the Delta) and Lake States (Michigan, Minnesota and Wisconsin). This is evident in Table 2-10.

TABLE 2-10. IRRIGATED LAND IN THE EASTERN UNITED STATES, 1967 AND 1977 (1000 acres)

	1967	1977
Northeast	440	371
Appalachia	--	414
Cornbelt	206	1,112
Missouri	118	776
Other Cornbelt	88	336
Lake States	129	966
Southeast	1,694	3,424
Delta	3,520	4,014
Total	5,989	10,301

Sources: Hanson and Pagano, September 1980. Basic data taken from the USDA' Conservation Needs Inventory of 1967 and National Resources Inventory of 1977

The expansion of eastern irrigation outside the Delta has been primarily on droughty soils in the Lake States and Southeast. Because of low moisture retention characteristics of these soils, plants come under moisture stress very quickly, even though in an average year rainfall is ample to support plant growth (Hanson and Pagano). The presence of these soils also accounts for most of the expansion of irrigation in Indiana, the Cornbelt state, except for Missouri, with the greatest amount of irrigated land. Where these soils prevail, supplemental irrigation is economical because it avoids yield losses when the rains fail momentarily.

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[11] This section is based on Hanson and Pagano (September 1980) on irrigation in the East outside the Mississippi Delta and on Shulstad et al. (July 1980) on irrigation in the Delta.

Hanson and Pagano conclude that most of the potential for future expansion in eastern irrigation, apart from the Delta, is in the Southeast, particularly in Georgia and Florida. Aside from the droughty soils in those states, their growing season is long enough to permit double-cropping, and irrigation provides a timely water supply. Conservation tillage, of increasing importance in the Southeast, also encourages double-cropping by saving time between the harvest of the first crop and planting of the second.

Most of the irrigation in the Southeast is by onfarm pumping from groundwater or small streams or ponds on the farmer's property. Both ground and surface water supplies are ample relative to present and future competing demands for them. Hence, farmers in the Southeast are not likely to feel the competing pressures for water that their counterparts in the West must contend with. While in Georgia the depth to groundwater is some 250 feet (Sloggett, 1979), the aquifer is artesian, with enough pressure to make pumping requirements relatively modest. Consequently, rising real costs of energy will not inhibit the spread of irrigation by groundwater in the Southeast as they promise to do in the West.

Despite the prospect for increased irrigation in the Southeast, the impact on the growth of production and yields of the crops of interest to this study is likely to be small. Hanson and Pagano cite a 1977 federal government inter-agency Task Force report on irrigation which estimates the maximum irrigable area in the East, including the Delta, at 26 million acres. The study by Shulstad et al. estimates that there are 17 million potentially irrigable acres in the Delta. The implication is that there are some 9 million potentially irrigable acres in the East, apart from the Delta. Table 2-10 indicates that in 1977 there already were some 6 million acres of eastern irrigation outside the Delta. Even if all of the remaining irrigable but not yet irrigated land were in the Southeast, and it is not, the potential for expansion would appear to be only on the order of 3 million acres. Table 2-5 shows that in 1977 there were 31.6 million acres of cropland in the Southeast. Hence an increase of 3 million irrigated acres would be only about 10 percent of the cropland base of the region, not enough to have a major impact on the growth of regional production.

Hanson and Pagano, drawing on the 1974 Census of Agriculture, show that in that year only 5.5 percent of the irrigated land in the Southeast was in crops of interest to this study. One-third of the land was in orchards, 25 percent was in pasture, 12 percent was in vegetables and the rest in various minor crops. While corn and soybeans are expected to be much more important in additional irrigation than at present, they are not likely to account for all of the prospective growth.

In contrast, the study by Shulstad et al. suggests that expansion of irrigation in the Delta could have a significant impact on production and yields in that region, particularly of soybeans. Shulstad et al. consider numerous alternative combinations of crop prices, input costs, yields and crop rotations, and most indicate that it would be economical to irrigate all of the some 17 million acres in the Delta judged by the authors to have the physical characteristics consistent with irrigation. In the alternatives considered the amount of irrigated soybean land varies from 8 to 12 million acres.

Table 2-5 indicates that there were 4.1 million acres of irrigated land in the three Delta states in 1977. With most of Missouri's 776,000 acres included in this, as they are in the study by Shulstad et al., presently irrigated land in the Delta is almost 5 million acres. If the estimate by Shulstad et al. of potential is correct, we can expect a substantial expansion of irrigated land in the Delta, much of it in soybeans. The implications of this for yield projections in the Delta are considered in Section 4.

CONCLUSIONS ON PRICES OF INPUTS

We conclude that real prices of energy will rise at an average annual rate of about 2 percent from 1980 to the end of the century and beyond, with natural gas prices increasing substantially more than this. This will put upward pressure on prices of nitrogen fertilizer and on the costs of pumping water for irrigation. Higher prices of natural gas combined with rising costs of construction in the fertilizer industry likely will cause real prices of fertilizer to rise by 1985, even though demand does not press hard on capacity. We assume that real nitrogen prices will continue to rise to the end of the century and beyond. Declining water tables in the High Plains likely will reinforce the effect of higher energy prices on costs of pumping in that region, and throughout the West growing nonagricultural demands for water likely will increase its cost to agriculture.

The amount of irrigated land in the East, apart from the Mississippi Delta, is expected to increase, particularly in the Southeast, but the impact on trends in yields and production of crops of interest to this study will probably be small. The expansion of irrigated soybean production in the Delta, however, could be significant.

In short, for most farmers real prices of energy, fertilizer and irrigation water, the key ingredients of land-saving technologies, are expected to rise for the next several decades, in contrast to their behavior in the two decades prior to the early 1970s. Other things the same, this would make land-using technologies more attractive to farmers (except perhaps for those in the Southeast and the Delta) than they were in those earlier decades. However, farmers' choices will be influenced by the prospective productivity of the alternative technologies and by the costs of increasing the supply of cropland. Productivity is examined in the next section and the supply of land in the one after that.

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SECTION 3

TRENDS IN PRODUCTIVITY AND CROP YIELDS IN THE UNITED STATES

INTRODUCTION

We would like to be able to measure trends in the productivity of land-using and land-saving technologies as a basis for projecting these trends into the future. These projections, in combination with the projections of input prices discussed in the previous chapter, would provide a basis for judging how farmers in the future might choose between the two types of technology.

We concluded in the last chapter that real prices of energy, fertilizer, and (for most farmers) irrigation water likely will rise over the next several decades, in contrast to their movement in the two decades prior to the early 1970s. This would make land-using technologies look more attractive in the future than in that earlier period, other things the same. However, if the productivity of land-saving technologies were to rise more than in the earlier period, this would tend to offset the effect of higher input prices on the relative attractiveness of land-using and land-saving technologies. Should the productivity of land-saving technologies rise less than in the earlier period this, of course, would reinforce the effect of input prices in making land-using technologies look more attractive.

We posit a situation in which the "typical" farmer, faced with rising demand for crops, knowing present prices of inputs, and having expectations about their future prices, asks himself the question, what mix of land and other inputs should I choose in response to higher demand? We assume that the desire to maximize profits will be the dominant criterion of choice. Consequently, the farmer will tend to choose that combination of inputs which, given input prices, yields the highest output per unit of total input, i.e., that combination with the highest total productivity.

This suggests that examination of trends in total productivity would provide insights about farmers' future choices among technologies. We have not undertaken such an examination, however, because we have serious reservations about the accuracy of the USDA's index of total productivity, especially in the period since 1972. The argument underlying these reservations is given in appendix B. Suffice it to say here that the sharp decline in the last several decades in the quantity and increase in price of farm labor relative to the quantities and prices of other inputs, particularly fertilizer and farm machinery, creates a fundamental problem in constructing an

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unambiguous index of total input, hence of movements in total productivity. In addition, it appears to us that the way land is handled in the USDA's index of total productivity significantly underestimates the role of land in expanding production after 1972, thus overestimating the increase in total productivity.[1]

For these reasons we have focused our attention on crop yields instead of on total productivity. This has several advantages. One is that our interest in this study is in the resource and environmental impacts of crop production, not total production. Another is that examination of trends in yields provides a basis for projecting them, and therefore of converting our projections of production into projections of land used for crops. A disadvantage of focusing on yields is that they provide only a partial measure of productivity, but farmers' choices are conditioned by total productivity. However, in attempting to explain the behavior of yields we necessarily deal with trends in the productivity of fertilizers and other components of land-saving technologies. This provides insights to movements in total productivity even though we do not measure it directly.

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TRENDS IN YIELDS: ALL CROPS

Table 3-1 gives information about actual and trend yields of all crops between 1960 and 1979. The trend values are based on actual yields in 1950-1972. Column (3) of the table indicates that in each year after 1972 actual yields were less than trend yields established in the period 1950-1972. Not only did actual yields fall short of trend yields in every year 1973-1980 but the average annual deviation from trend in that period was 4.3 times as large as in 1950-1972. In no period from 1950-1972 did actual yields fall short of trend yields for as many as eight years in a row. (The maximum was four years, 1954-1959.) The yield experience in 1973-1980, therefore, suggests that the trend of yields in those years was lower than in 1950-1972.

Table 2-1 in the previous section indicates that the ratio of all purchased inputs to cropland used for crops increased 60 percent from 1951 to 1972, then rose at a much slower rate from 1972 to 1979. The quantity of fertilizer per acre of harvested cropland increased 7 percent annually from 1951-1955 to 1972, but by only 1.3 percent per year from 1972 to 1979. The amount of harvested cropland declined from an average of 338 million acres in 1951-1955 to 289 million acres in 1972, then rose to 331 million acres in 1978 and to 343 million acres in 1979 (USDA Feb. 1981).

Given these changes after 1972 in behavior of ratios of nonland inputs to land and in the amount of harvested cropland, the slower growth of crop yields after 1972 is not surprising. Indeed it is the expected result of the reduced shift to land-saving technologies. With respect to post-1972

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[1] For a discussion of the index number problems, and others affecting the USDA's measure of total productivity change, see USDA, Feb. 1980.

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TABLE 3-1. YIELDS FOR ALL CROPS (1967=100)

	(1) Actual Yields	(2) Trend of Actual Yields	(3) Actual Yields / Trend Yields	(4) "Required" Yields	(5) "Required" Yields / Trend Yields
1960	88	88	1.00		
61	92	90	1.02		
62	97	92	1.05		
63	99	95	1.04		
64	96	97	.99		
1965	102	99	1.03		
66	99	101	.98		
67	100	103	.97		
68	105	106	.99		
69	110	108	1.02		
1970	104	110	.95		
71	112	112	1.00		
72	118	114	1.04		
73	113	117	.97	124	1.06
74	103	119	.87	115	.97
1975	110	121	.91	126	1.04
76	110	123	.89	126	1.02
77	115	126	.92	136	1.08
78	119	128	.93	137	1.07
79	126	130	.98	150	1.15
1980	114	132	.86	137	1.04

<ins>Average deviation from trend</ins>
1950-1972: 2.9
1973-1980: 12.5

Source: USDA, Feb. 1981 for 1950-1979. 1980: Harvested cropland from Thomas Frey, USDA; index of crop production from USDA, Jan.-Feb., 1981.

Note: Column (1): Index of crop production divided by acres of cropland harvested, 1967=100.
Column (2): Arithmetic trend of actual yields 1950-1972, projected 1973-1980.
Column (3): Yields that would have been "required" to produce each year's output 1973-1980 if the amount of cropland harvested had remained the same as in 1972.

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experience the fact that some of the land brought under crops after 1972 was of lower natural fertility than land already in crops also contributed to slower growth of yields. (More on this in Appendix C.)

For these reasons, the slower growth of crop yields after 1972 does not necessarily indicate that the slower shift to land-saving technologies occurred because the productivity of these technologies, as measured by yields, had declined, or was rising less rapidly. At least some, and perhaps all of the yield behavior was a result of the slower shift, not a cause of it.

To provide some insights into this cause-and-effect relation between yield behavior and the behavior of technology after 1972, we constructed an index of "required" yields for 1973-1979. We asked the question, suppose farmers had produced the actual amounts of crops in those years with the same amount of cropland harvested as in 1972: what levels of yield would have been required to do that? Those yields are in column (4) of table 3-1. We then asked the question, given the yield experience of 1950-1972, could farmers reasonably have expected to achieve the yields shown in column (4)? We believe column (5) indicates that the farmers' response would have been negative; that, with the exception of 1974 (when production was depressed by exceptionally bad weather), the "required" yields would have appeared to be out of reach, even if farmers had expected the pre-1972 trend in yields to continue. To achieve the higher levels of production after 1972, therefore, farmers would have concluded that more land would have to be brought into production.

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This argument indicates that the productivity of land-saving technologies, as measured by crop yields, was not rising fast enough before 1972 to meet the demand for crop production in 1973-1979 without an increase in the amount of land in production. The argument does not indicate, however, that the rate of increase of productivity of these technologies was declining. These conclusions are useful for our purposes, but they do not lead as far as we would like because they deal with crop production as a whole. Our interest is in specific crops, or groups of crops: wheat, feedgrains, soybeans, and cotton. Examination of the yield experience of these crops is the next step.

YIELDS OF GRAIN AND SOYBEANS[2]

The analysis is focused on the behavior of yields of principal grains and soybeans in the United States from the late 1940s to the late 1970s, seeking to measure the contribution of various factors to changes in yields over this period. We identify two broad categories of factors. One we call

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[2] We also are interested in production and yields of cotton. However, there has been no trend in cotton yields since the mid-1950s and we anticipate no dramatic change in this. Moveover, even if there were such a change the amount of land in cotton would remain small relative to land in grains and soybeans. For these reasons we do not consider trends in yields of cotton.

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pure shift factors and the other pure yield factors. Yields for a given crop differ among states. Should the relative distribution among states of land in that crop change over time, national average yields will change even if yields in each state remain the same. We say this change in national average yields is attributable to pure shift factors. Changes over time in yields within each state we say reflect pure yield factors.

We distinguish three pure yield factors: (1) weather, (2) land quality and (3) technology, by which we mean everything affecting yields within states except weather and land quality. We consider two components of technology: (a) fertilizers; and (b) irrigation.

We have made quantitative estimates of the contributions of pure shift and pure yield factors to the behavior of corn, wheat, sorghum, and soybean yields for selected periods from 1946-1950 to 1975-1976. Within the set of pure yield factors we have made estimates of the effect of weather and of land quality on yields of corn, wheat, and soybeans over these same periods. We have not estimated the yield effects of fertilizer on these crops, and our estimates of irrigation effects are incomplete. There is information available, however, about both fertilizer and irrigation which permits some judgments to be drawn about the effects of these inputs on trends in yields.

The analysis, which is quite detailed and technical, is in Appendix C. Here we present only a summary of the principal conclusions.

Our analysis shows that growth of yields within states was far more important than shifts among states in explaining the behavior of yields of corn, sorghum, wheat and soybeans from 1946-1950 to 1971-1973. We have examined corn and soybean yields in the Cornbelt and wheat yields in the Plains states to isolate the effects on yields of (1) weather, (2) land quality, and (3) technology. We particularly consider yield behavior before and after 1972 because of the slower growth of yields after that date. For soybeans we conclude that weather alone could account for post-1972 yield behavior. Wheat yields, however, clearly cannot be attributed to weather alone, and it is doubtful that corn yields can be.

We therefore examine the effect on yields of the expansion of land in wheat and corn after 1972, on the assumption that the additional land is inferior to land already in production. We conclude that the increment of wheat land in the five Plains states probably would not explain much more than 10 percent of the difference between actual wheat yields and the trend value of weather-adjusted yields in 1977-1980, and that the weather could not likely explain the remaining 80+ percent. The increment of corn land in the Cornbelt explains roughly two-thirds of the yield shortfall, and the remaining one-third may in fact be explained by weather.

For wheat at least it appears that technology contributed less to the growth of yields after 1972 than before. This conclusion is supported by the fact that per-acre applications of fertilizer to wheat land rose more slowly after 1972 than before. The slower growth in fertilizer applications per acre was even more marked for corn than for wheat. Although it appears

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that the weather and additional land may be sufficient to explain the shortfall in corn yields in 1977-1980, the slower growth in per-acre fertilizer use likely contributed something also.

The expansion of irrigated production of wheat and corn from 1950 to 1977 was substantial in percentage terms, and yields of irrigated land in these crops rose also. However, irrigated production of these crops was small in relation to dryland production, and dryland yields also rose sharply. Consequently, the contribution of irrigation to the growth of national yields of corn and wheat was small. We cannot determine whether this contribution declined after 1972 for lack of data, but qualitative information from the Plains region suggests that it did not.

The analysis of yields of wheat, corn and soybeans leads to no definite conclusion about the role of productivity in inducing the slower shift to land-saving technologies after 1972. The slower growth of per-acre fertilizer use on wheat and corn after that date does not necessarily reflect diminishing marginal productivity of fertilizers. It could as well be explained by the increase in the real price of fertilizer. There is nothing in our analysis, however, to suggest an upward shift in the trend of productivity of land-saving technologies. The main question is whether the pre-1972 trend has continued or whether it has shifted downward. We conclude that continuation of the present trend of productivity of land-saving technologies will not make these technologies look more attractive in the future than in the past. Given our projected rise in real prices of energy, fertilizer, and irrigation water, we conclude, therefore, that the slower shift toward land-saving technologies that set in after 1972 will continue over the indefinite future. In this event, our projections of increased production likely mean that the demand for cropland will continue to rise, suggesting two questions: how much might the demand for land rise, and what will be the supply response? We examine these questions in the next section.

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SECTION 4

THE DEMAND FOR AND SUPPLY OF CROPLAND

INTRODUCTION

We have argued that prospects for the prices and productivity of land-saving inputs suggest that farmers will continue to select technologies from the land-using end of the spectrum. If this happens, how much land would American farmers need to produce the levels of crop output projected in Section 1? This is the first of two principal questions addressed in this section. The second question is in two parts: (a) Would the present supply of cropland be adequate to meet the projected demand? (b) If present supply is not adequate, what would be the effect on the economic cost of agricultural land of converting non-cropland to crops?

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We proceed in three steps: (1) projection of regional production of each crop; (2) projection of regional yields, and (3) analysis of the present and potential supply of land, by region, in relation to projected demand. A detailed account of the first two steps is in Appendix D. Here we give a summary of the underlying arguments. The complete argument underlying the third step is presented in this section, however.

REGIONAL PROJECTIONS OF PRODUCTION

These projections are derived from projections of regional shares of national production. Table 4-1 shows actual shares for various years and projected shares for 1985 and 2010. The table indicates that for the past years shown the regional shares of wheat, feed grains, and soybeans were quite stable in the sense that the absolute changes in percentages generally were small. The maximum change was 7.5 percentage points in the share of the Northern Plains in wheat production between 1970-72 and 1976-78. This decline was almost exactly offset by an increase in the shares of the Southern Plains and Lake States in wheat production.

A check of data for the 1950s, not shown here, indicates that regional shares in those years were comparable to those shown in Table 4-1, with a couple of exceptions. In the 1950s the Cornbelt had 14-15 percent of wheat production, compared to the 10-12 percent shown in Table 4-1. Most of the decline in the Cornbelt's share of wheat production since the 1950s was offset by increases in the shares of the Southern Plains and Pacific states.

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The other significant change since the 1950s was a decline in the Cornbelt's share of soybean production from about 68 percent to the 56-60 percent shown in Table 4-1. Most of this was offset by an increase in the Delta's share of soybean production from about 9 percent in the 1950s to the 14-16 percent shown in the table and by an increase in Appalachia's share from about 5 percent to 7-8 percent.

The distinctive feature about the regional distribution of cotton production is its shift from the Southeast and Delta to the Southern Plains (mostly Texas); Mountain states (mostly Arizona); and Pacific (California). According to Collins, Evans, and Berry (p. 21) this shift reflects better conditions for growing cotton in the West than in the Southeast and Delta. In particular fewer pest problems and better water control through irrigation have led to lower production costs in Texas, Arizona and California than in the two more eastern regions.

The stability of regional shares in production of grains and soybeans suggests that radical shifts in the regional location of production of these crops are unlikely over the next several decades.[1] We do expect some changes, however. These are: (1) an increase in the share of the Southeast in corn and soybean production and of the Mississippi Delta in soybean and wheat production. In both cases the reasons for expecting increased shares are the potential for supplemental irrigation, discussed in Section 2, and the availability of land now in pasture and forest with potential for conversion to cropland, (2) An increase in the share of the Southern Plains in wheat production is expected, continuing a trend evident for some years and consistent with that region's relatively abundant supply of land with potential for conversion to crops. (3) The decline in the share of the Mississippi Delta in cotton production is expected to continue, with the Southern Plains (mostly Texas) and the Pacific (California) gaining. As noted above, this shift has been underway for some time and reflects lower costs of cotton production in Texas and California. Texas is expected to gain also at the expense of New Mexico and Arizona (the two Mountain states that grow cotton), reflecting the increasing cost and scarcity of water for irrigation. Most of the land in cotton in those states is irrigated compared with 40-45 percent in Texas. Most cotton acreage in California (the Pacific state that grows cotton) is irrigated, but California has other cost advantages sufficient to maintain its share of production at a relatively high level.

NATIONAL AND REGIONAL PROJECTIONS OF YIELDS

If we are right in thinking that in the future farmers are likely to continue to favor relatively land-using technologies, as they have since 1972, then the behavior of yields since 1972 should provide a guide for projections of future yields. The trend of yields of the various crops

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[1] The effect of higher energy prices on transportation costs may cause some shifts in the regional distribution by production not captured in our projections. We were unable to explore this possibility in this study.

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Table 4-1. REGIONAL SHARES OF CROP PRODUCTION (percent)*

	North-east	Lake States	Corn-belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Moun-tain	Pacific
Wheat										
1967-69	1.9	4.3	12.1	40.5	1.9	.7	1.7	11.7	15.3	9.9
1970-72	1.3	4.3	10.2	45.2	2.1	.8	.9	8.7	15.3	11.2
1973-75	1.3	6.2	10.2	39.8	1.9	.6	.8	13.1	14.9	11.3
1976-78	1.1	7.5	11.1	37.7	1.6	.4	1.2	12.5	15.4	11.5
1985	1	7	10	36	1	b	1	15	16	13
2010	1	6	5	34	1	1	7	16	16	13
Feedgrains										
1960-64	3	13	46	17	5	3	1	6	3	3
1965-69	3	13	48	17	4	3	1	6	3	2
1970-74	3	13	46	18	4	3	†	7	3	2
1975-78	3	13	47	18	4	3	†	6	3	2
1985	3	13	46	16	5	4	0	6	5	2
2010	3	15	46	15	5	4	0	6	4	2
Soybeans										
1967-69	1.1	8.2	57.6	4.8	6.6	4.1	16.4	1.1	--	--
1970-72	1.0	7.9	59.7	3.9	6.8	4.5	15.5	.6	--	--
1973-75	1.2	8.5	56.8	4.7	7.8	5.9	14.2	.9	--	--
1976-78	1.3	8.4	56.2	4.2	7.8	5.7	14.9	1.4	--	--
1985	1	8	55	4	8	6	16	2	--	--
2010	1	8	48	5	8	[illegible]	16	4	--	--
Cotton										
1967-69	--	--	2.0	--	4.6	9.4	28.1	34.7	8.1	13.1
1970-72	--	--	3.1	--	5.7	10.7	31.9	30.9	6.2	11.6
1973-75	--	--	1.9	--	4	8.9	25.8	32	8.2	19.2
1976-78	--	--	1.6	--	2.5	4.7	23.3	38	7.8	20.1
1985	--	--	1.6	--	1	3	19	40	10	25
2010	--	--	1	--	2	3	14	47	8	5

Notes to Table 4-1.

Source: USDA, Agricultural Statistics, various years. Note that the years shown for feedgrains are different from those for wheat, soybeans and cotton. This reflects the way the data were compiled, and has no significance for the projections.

*May not add to 100 because of rounding.

†Less than .5 percent.

The states in each region are as follows: Northeast--all of New England plus New York, New Jersey, Pennsylvania, Delaware, and Maryland; Lake states--Michigan, Minnesota, and Wisconsin; Cornbelt--Ohio, Indiana, Illinois, Iowa, Missouri; Northern Plains--North Dakota, South Dakota, Nebraska, Kansas; Appalachia--Virginia, West Virginia, Kentucky, Tennessee, North Carolina; Southeast--South Carolina, Georgia, Florida, Alabama; Delta--Arkansas, Mississippi, Louisiana; Southern Plains--Oklahoma, Texas; Mountain--New Mexico, Arizona, Nevada, Colorado, Wyoming, Montana, Idaho, Utah; Pacific--California, Oregon, Washington.

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since 1972 is obscured, however, by extreme variations in weather. The weather effects are particularly troublesome because they severely depressed yields early in the period (see the indexes of weather effects for corn and soybeans in Tables C-2 and C-3) and elevated them in 1978 and 1979. (The effect of weather was strongly adverse in 1980, however.) This pattern of weather effects gives a sharp upward tilt to the trend of yields of corn and soybeans, and to a lesser extent of wheat, between 1973 and 1980.

C-2
+
C-3

X

Table 4-2 shows national yields of these crops, and of cotton, from 1971 to 1980. Table 4-3 shows average yields for 1975/78 and projections to 1985 and 2010 for the nation and for the ten USDA producing regions. The eight years 1973 to 1980 obviously provide an uncertain base from which to project national and regional yields. Consequently we saw little justification for projecting trends derived from mathematical fits to the 1973-1980 data. Instead, for each crop we examined the behavior of national yields and yields for the two or three major producing regions, and made judgmental projections on that basis, assuming that the trend of national yields would be dominated by trends in the major regions. Yields in other regions were then projected proportionately to one another and so as to be consistent with the projections for the nation and the major regions.

These obviously are rough-and-ready procedures, and the resulting projections of yields are subject to an uncomfortably large margin of error. The main issue with respect to yields, however, is whether their post-1972 trend behavior is more likely to presage the future than their pre-1972 trends. Believing as we do that the prices and productivities of yield-increasing inputs will behave more as they did after 1972 than before that

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date, we have to conclude that the post-1972 trends in yields are more indicative of the future than pre-1972 trends. If we are correct in this, our projected yields, despite the large error to which they are subject, will be closer to actual yields in 1985 and 2010 than if we were to assume that the pre-1972 trends will reassert themselves.

The yield projections have enormous implications for projections of land use and resulting economic and environmental pressures on the nation's land and water resources. The effect of alternative yield projections is particularly evident by 2010. Given our projections of crop production, it is not too much to say that yield behavior will determine whether or not the nation's agriculture will encounter serious economic and environmental problems over the next several decades. We take the yield projections in Table 4-3 as a point of departure in our subsequent analysis. We emphasize here, however, as we did in the conclusions, that the results of that analysis, particularly as they bear on the severity of future environmental pressures, depend crucially on our projections of yields.

Table 4-2. YIELDS IN THE UNITED STATES OF WHEAT, FEEDGRAINS, SOYBEANS AND COTTON

	Wheat	Feedgrains	Soybeans	Cotton
	(metric tons/acre)			(lbs./acre)
1971	.92	1.77	.75	438
1972	.89	1.93	.76	507
1973	.86	1.81	.75	520
1974	.74	1.49	.63	442
1975	.84	1.75	.78	453
1976	.82	1.82	.71	465
1977	.83	1.88	.83	520
1978	.86	2.08	.81	421
1979	.93	2.31	.87	551
1980	.89	1.95	.73	421

Sources: USDA, 1980 for 1971-1979, and May, 1981 for 1980.

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Table 4-3. YIELDS IN THE UNITED STATES OF WHEAT, FEEDGRAINS AND SOYBEANS (metric tons/acre)

	1975/1978			1985			2010		
	Wheat	Feedgrains	Soybeans	Wheat	Feedgrains	Soybeans	Wheat	Feedgrains	Soybeans
Nation	.84	1.88	.78	.91	2.28	.87	1.08	2.94	1.10
Northeast	.94	1.96	.74	1.07	2.17	.80	1.14	2.79	.98
Lake States	.95	1.95	.86	1.03	2.36	.93	1.15	3.04	1.14
Cornbelt	1.07	2.37	.90	1.16	2.87	.99	1.33	3.70	1.30
Northern Plains	.76	1.62	.74	.83	1.96	.80	.92	2.53	.98
Appalachia	.90	1.87	.67	.97	2.10	.72	1.09	2.72	.89
Southeast	--	1.35	.59	--	1.52	.70	*	1.93	.94
Delta	.95	--	.63	1.03	--	.74	*	--	1.00
Southern Plains	.66	1.62	.67	.71	1.80	.72	.81	2.30	.89
Mountain	.82	1.35	--	.89	1.52	--	.99	1.94	--
Pacific	1.23	1.47	--	1.33	1.68	--	1.49	2.29	--

Sources: 1975/1978 from USDA, Agricultural Statistics, various years. 1985 and 2000 projected as described in the text.

[*] Assumes that all wheat in the Southeast and Delta is double-cropped with soybeans.

DEMAND FOR AND SUPPLY OF CROPLAND

Demand for Cropland

The demand curve for cropland shifts to the right in response to rising demand for crops and to farmers' choices of the most economical mix of land and other inputs with which to meet crop demand.[2] We take yields to reflect the outcome of these choices. Taken together, therefore, projections of crop production and yields define projected demands for cropland. These are shown in Table 4-4. The table shows harvested cropland in main crops (feedgrains, soybeans, wheat and cotton) and in other crops. It also shows other uses of cropland. Since the late 1960s the amount of land in "other crops" has been quite stable at around 90 to 95 million acres. About two-thirds of this land consistently is in hay. Land in hay reached a peak of 77.6 million acres in 1944, then declined steadily to 60.9 million acres in 1968. It has varied narrowly around 60 million acres ever since. We have assumed that land in hay will be 60 million acres in 1985, but that it will decline to 50 million acres in 2010 as hay finds increasing difficulty competing with other higher-valued uses of the land. We assume that non-hay "other crops" will occupy the same amount of land in 1985 and 2010 as in 1977. To do better than this would require more analysis of future demand for these crops, and of their yields, than we are in a position to make.

In each year from 1958 to 1977, crops failed on from 5 million to 10 million acres, the average being 7.4 million acres. In projecting 10 million failed acres, the figure for 1977, we may be somewhat on the high side, but any reasonable alternative would make no significant difference in our projections of total demand for cropland.

In the same twenty-year period just mentioned, land in fallow varied between 30 million acres and 41 million acres, the average being 33.9 million acres. Virtually all of the land in fallow is in the main wheat growing areas. Fallowing restores soil moisture after harvest, and is essential to economical production of wheat in the semi-arid West. The record suggests that this imperative sets a minimum of about 30 million acres for land in fallow. We have used that figure in both 1985 and 2010.

Data for idle cropland are available only for agricultural census years. In the most recent four such years, the amounts of idle cropland were as follows:

1954	33 million acres
1964	52 million acres
1969	51 million acres
1974	20 million acres

Source: USDA *Agricultural Statistics* 1973 and 1977. 1978 agricultural census data for idle cropland were not available at this writing.

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[2] We here leave aside other reasons for demanding cropland, e.g., as an inflation hedge or tax haven.

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Table 4-4. **PROJECTIONS OF DEMAND FOR CROPLAND (millions of acres)**

	1985						2010					
	Harvested						Harvested					
	Main Crops	Other Crops	Failed	Fallow	Idle	Total	Main Crops	Other Crops	Failed	Fallow	Idle	Total
Northeast	5.1	8.0	.2	--	1.0	14.3	5.9	7.1	.2	--	1.0	14.2
Lake States	23.9	13.0	.8	--	2.8	40.5	30.3	12.7	.8	--	2.8	46.6
Cornbelt	81.1	10.1	.7	--	2.9	94.8	92.3	5.1	.7	--	2.9	101.0
Northern Plains	53.1	20.4	3.3	15.9	3.0	95.7	63.8	20.6	3.3	15.9	3.0	106.6
Appalachia	13.8	6.4	.3	--	1.9	22.4	18.6	5.6	.3	--	1.9	26.4
Southeast	12.5	4.6	2.0	--	1.4	20.5	22.1	4.4	2.0	--	1.4	29.9
Delta	16.6	3.5	.3	--	1.4	21.8	20.6	3.2	.3	--	1.4	25.5
Southern Plains	32.3	6.2	1.2	.8	3.3	43.8	42.8	5.5	1.2	.8	3.3	53.6
Mountain	20.9	10.6	1.1	9.5	1.5	43.6	24.7	9.3	1.1	9.5	1.5	46.1
Pacific	11.5	9.4	.2	3.6	.8	25.5	13.8	8.7	.2	3.6	.8	27.1
Nation	270.8	92.2	10.1	29.8	20.0	422.9	334.9	82.2	10.1	29.8	20.0	477.0

Notes: Main crops are wheat, feedgrains, soybeans, and cotton, projected as described in the text and in Appendix D. Land in "other crops" is mostly hay (65 percent for the nation in 1985 and 60 percent in 2010). The projection for non-hay "other crops" is the amount of land in these crops in 1977. The projections for failed and fallow land also are the same as 1977. Idle land is the same as 1974.

The high figures for 1964 and 1969 reflect the policy then in effect of encouraging farmers to take land out of production; the low figure for 1974 reflects the abandonment of that policy and the influence of high-crop prices in stimulating intensive use of the land. It is significant that despite this stimulus there still were some 20 million acres of idle cropland in the country in 1974. According to land use specialists at the USDA, some cropland inevitably is idle every year for reasons that vary widely from place to place, and 20 million acres probably is close to the minimum amount of such land. That is the basis for our projection of idle land.

Supply of Cropland

Table 4-5 shows two estimates of the amount of cropland in the United States in 1977. We have no information that would account for the differences between the estimates, but take some comfort from the fact that the difference between the totals is relatively small. We work with the USDA's National Resources Inventory (Feb. 1980) because in addition to data on the amount of present cropland it also includes estimates of the amount of land potentially convertible to cropland, amounts of erosion from cropland, and other useful information.

Table 4-6 shows data from the NRI for the present (1977) and potential supply of cropland, and projections of the demand for cropland as percentages of present and potential supply. The projections indicated that by 1985 the nationwide demand for cropland would exceed the present supply by 2.5 percent, or about 10 million acres. By region the situation would be quite diverse, demand being weak relative to present supply in the Northeast and Lake states and relatively strong in the Southeast. The greatest absolute shortage of land would be about 5 million acres in the Cornbelt, indicating that half of the projected nationwide deficit would be in that region.

By 2010 the nationwide demand for cropland would exceed the present supply by 15.6 percent, or about 64 million acres. Only in the Northeast would demand fall short of supply, and in the Southeast demand would exceed present supply by over 70 percent. The largest absolute deficits would be in the Northern Plains (12 million acres), the Southern Plains (11.4 million acres) and the Cornbelt (11.1 million acres).

Given our projected levels of production and yields of main crops, there would be two possible responses to the set of demand-supply relations indicated in Table 4-6: (1) a reduction in the amount of land devoted to other crops, or that is in fallow or that is idle; (2) conversion to crops of land now in pasture, forest, or range.

These responses are not independent of one another, being linked by the cost of each relative to the other. We have more to say below about the costs of land conversions, but we believe that conversions likely would be much more important than shifts in present patterns of use of cropland. It is not likely that idle land can be much reduced below the projected 20 million acres, for reasons given earlier. We indicated above that the maintenance of some 30 million acres in fallow seems an imperative of crop

Table 4-5. ESTIMATES OF THE AMOUNT OF CROPLAND IN THE UNITED STATES IN 1977, BY MAJOR USE[*]

(million acres)

	ESCS[†]	NRI[‡]
Row crops and close grown crops	292.1[§]	308.1
All hay	60.7	63.4
Fallow	30.0	29.3
Tree and bush crops and vineyards	3.4	5.5
Idle	20.0[#]	—
Other	—	6.8
Total	406.2	413.2

[*] Excludes cropland used only for pasture, which was 83.5 million acres in 1974.

[†] The Economics, Statistics and Cooperatives Service of the USDA.

[‡] The National Resources Inventory, conducted by the Soil Conservation Service (USDA, Feb. 1980).

[§] Planted acres of all crops except hay, tree and bush crops and vineyards, from USDA, January 15, 1980. Includes land on which crops failed.

[#] From the 1974 Agricultural Census. The figure for 1977 is not known, but for reasons given in the text it was unlikely to have been less than 20 million acres.

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Table 4-6. SUPPLY OF AND DEMAND FOR CROPLAND

	Supply of Cropland (million acres)			Demand for Cropland as Percent of Supply					
				1985			2010		
		Present Plus			Present Plus			Present Plus	
	Present	High Potential	High and Medium Potential	Present	High Potential	High and Medium Potential	Present	High Potential	High and Medium Potential
Northeast	16.9	18.0	21.6	84.6	79.4	66.2	84.0	78.9	65.7
Lake States	44.1	46.4	52.3	91.8	87.3	77.4	105.7	100.4	89.1
Cornbelt	89.9	94.7	104.3	105.5	100.1	90.9	112.4	106.7	96.8
Northern Plains	94.6	99.7	112.5	101.2	96.0	85.1	112.7	106.9	94.8
Appalachia	20.8	25.5	35.1	107.7	87.8	63.8	126.9	103.5	75.2
Southeast	17.5	22.4	33.3	117.1	91.5	61.6	170.9	133.5	89.8
Delta	21.2	24.3	31.2	102.8	89.7	69.9	120.2	104.9	81.7
Southern Plains	42.2	47.4	62.2	103.8	92.4	70.4	127.0	113.1	86.2
Mountain	42.2	45.4	56.4	103.3	96.0	77.3	109.2	101.5	81.7
Pacific	23.2	24.8	28.4	109.9	102.8	89.8	116.8	109.3	95.4
Nation	412.6*	448.6	537.1	102.5	94.3	78.7	115.6	106.3	88.8

Sources: Present and potential cropland from USDA, Feb. 1980. Definitions of high and medium potential land are given in the text. Demand for cropland from table 4.4.

*Excludes 293,000 acres in Hawaii and 363,000 in the Caribbean.

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production, particularly wheat, in the semi-arid West. However, if pressure on the land base in that region mounts, as Table 4-6 indicates, farmers might find ways to reduce the amount of land in fallow without fatally compromising the economics of wheat production. In this connection it is worth noting that in a run of the Iowa State model in which the total amount of cropland and its regional distribution corresponds closely to our projections, the model puts 22.5 million acres in fallow.

Conceivably, some of the expanded production of main crops could be on land now in hay and other crops. In fact, we have projected a decline in hayland from 60 million acres to 50 million acres in 2010. (The run of the Iowa State model, mentioned above, put 55 million acres in hay in 2010.) Apart from hay the most important land-using crops among "other crops" are corn for silage (8.5 million acres in 1977-79), sunflower (2.2 to 5.4 million acres), rice (2.2 to 3.0 million acres), peanuts (1.5 million acres) and potatoes, sugar beets, flaxseed and edible beans (all 1 to 1.3 million acres). No doubt some of the land in these crops could be shifted to production of main crops. How much flexibility there is in this connection would depend upon cross-demand and -supply elasticities among main and minor crops, matters which we cannot explore. Any significant shift of land out of minor crops, however, surely would raise their prices, the sharper the rise the more limited the shift.

The various substitution possibilities perhaps would be sufficient to accommodate a good part of the 10 million acre deficit projected for 1985, but they would not likely contribute much to cover the 64 million acre deficit projected for 2010. Satisfying that excess demand surely would have to be done primarily by converting to crops land now in pasture, forest, or range.

According to the NRI there were in 1977 36 million acres of land in pasture, forest, and range with high potential for conversion to crops. An additional 88.5 million acres of such land were judged to have medium potential for conversion. Table 4-6 indicates that the high potential land would be sufficient to cover the excess demand for cropland in 1985, except perhaps in the Pacific region, and that the combination of high and medium potential land would be sufficient to cover the projected deficits in 2010 for every region. Before concluding that the potential supply of cropland would, in fact, be adequate, however, we must address two questions: (1) How much would it cost to convert the potential land and would farmers be willing to pay the cost? (2) How much of the present and potential supply of cropland will likely be lost to non-crop uses over the next several decades?

Costs of Land Conversion--

In the NRI land with high potential for conversion to crops was defined as that with "favorable physical characteristics" and of a sort which had been converted in the vicinity in the three years preceding the survey (1974-76). Commodity prices and development and production costs of 1976 were assumed. Medium potential land also has favorable physical characteristics, but conversion costs are estimated to be higher than for high potential land. There is no indication in the NRI that the price-cost relationships of 1976

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uniquely defined the economic conditions for conversion of land to crops, i.e., the NRI does not state that had prices been slightly lower or costs slightly higher conversions would not have occurred. The only statement is that under price-cost conditions prevailing in 1976 land of the sort indicated had been converted.

Table 4-7 shows prices received by farmers in 1976, 1979 and projections to 1985 and 1990. The table suggests that crop prices in 1985 and 1990 would favor conversion of land to corn and sorghum production but not to the other crops. If prices of inputs and conversion costs rise faster than yields, prospects for converting land to the other crops would appear to be even less favorable, and the profitability of converting to corn and sorghum might also become doubtful.

These statements must be taken with great caution, however. As noted above, the NRI does not indicate that the 1976 cost-price relations uniquely defined the terms of profitability of land conversion. Conceivably, about as much land as was converted would have been even if the cost-price relations had been less favorable than they were. In this connection it is noteworthy that in 1976 yields of wheat, corn, sorghum and soybeans were all below our projections for 1985.[3] If yields in 1985 are as we have projected them, this would offset some, if not all, of any increase in real prices of inputs that might occur between 1976 and 1985.

Changes in the amount of land in the various crops and in crop prices from 1976 and 1979 also suggest caution in interpreting the NRI's definition of the economic conditions underlying the estimates of convertible land. Table 4-7 indicates that changes in real crop prices from 1976 to 1979 would have favored the expansion of land in wheat and cutbacks in land in all the other crops. In fact, land planted to wheat in 1979 was 8.5 million acres less than in 1976; land in corn in 1979 was about the same as in 1976; land in sorghum, oats, and barley was down in aggregate about 7 million acres, and soybean acreage was up 21.4 million acres, an increase of 42.6 percent (USDA, 1979 and June 27, 1980). Total planted acreage in main crops rose 1.7 million acres, so the increase in land in soybeans could have been accommodated within the total amount of land in the main crops in 1976. Nevertheless, the sharp increase in the amount of land in soybeans despite the quite

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[3] Yields in 1976 and our projections for 1985 are as follows:

	1976	1985
	(metric tons/acre)	
Wheat	.82	.91
Feedgrains	1.82	2.28
Soybeans	.71	.87

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Table 4-7. **PRICES RECEIVED BY FARMERS FOR GRAINS AND SOYBEANS ($/bu.)**

				NIRAP (1979 $)	
	1976	1976 in 1979 $	1979	1985	1990
Wheat	$ 2.73	$ 3.38	$ 3.82	$ 3.09	$ 3.33
Corn	2.15	2.66	2.41	3.01	3.22
Sorghum	2.03	2.51	2.33	2.70	2.89
Oats	1.56	1.93	1.36	1.38	1.47
Barley	2.25	2.78	2.31	2.32	2.47
Soybeans	6.81	8.42	6.19	7.36	7.85

Sources: 1976 and 1979 from USDA, 1979 and 1980, respectively. The NIRAP projections are from Table 1-3 of this report. The GNP deflator was used to convert 1976 prices to 1979 dollars.

unfavorable movement in real soybean prices indicates we should not read too much into the price relations in Table 4-7 in judging whether farmers will want to convert pasture, forest, and range land to crops on the scale indicated in Table 4-6.

Studies done at Iowa State University and the University of Arkansas provide insights to the supply of potential cropland in Iowa and the Mississippi Delta (Shulstad, May, and Herrington for the Delta and Amos for Iowa). Both studies are based on detailed analysis of land conversion costs, including opportunity costs, and crop yields on various soil types in the Delta and Iowa. Table 4-8 is based on these studies. The estimates of convertible land in both regions assume that real prices of inputs will be one-third higher in 1985 than in 1978 and that crop prices will be as shown. Yields in Iowa are assumed to be 114 bushels per acre for corn and 40.4 bushels for soybeans. Yields in the Delta are those achieved by the top 10 percent of managers and are specified by soil type. Averages for each crop are not given. The Delta study assumes a 10 percent discount rate. The two estimates of convertible land in Iowa assume discount rates of 8 percent and 4 percent, respectively.

Table 4-8 suggests that NIRAP's projected prices for 1985 would not favor conversion of land to corn in either the Delta or in Iowa or to wheat in the Delta. The price comparisons tell only part of the story, however. We have not projected corn yields in Iowa separately, but typically corn yields in that state are 8-10 percent above feedgrain yields in the Cornbelt as a whole. If we assume that in 1985 corn yields in Iowa will be 8 percent above our projected yields for the Cornbelt, Iowa corn yields will be just enough above those assumed in the Amos study to offset the difference between the projected NIRAP price of corn and the price used by Amos.

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Our 1985 projections of soybean yields in the Cornbelt are virtually the same as those used by Amos for Iowa. The NIRAP price for soybeans would, therefore, imply expansion potential in Iowa greater than the Amos study shows. Whether this would also be true in the Delta is not clear. The study by Shulstad, May and Herrington indicated that in the scenario assuming output prices one-third higher than in 1978 the amount of convertible land was quite inelastic across the range of crop prices used. None of the prices for soybeans was as high as the NIRAP projections, however.

We conclude that the NIRAP price projections for 1985 and our projections of corn and soybean yields in the Cornbelt and of soybean yields in the Delta (we project no corn production in the Delta) are consistent with the estimates of convertible land in the Iowa and Delta studies. The NRI shows that there were 2 million acres of high and medium potential land in Iowa in 1977. The Amos study suggests that a quarter to half of this land could be profitably converted to production of corn and soybeans. If these projections hold for the Cornbelt as a whole, then 3.6 to 7.2 million acres of the 14.4 million acres of high-to-medium potential land in that region could be profitably converted to crops under the cost-price conditions projected for 1985. Our projections of the demand for land (Table 4-6) indicate that demand in the Cornbelt would exceed 1977 supply by 4.9 million acres in 1985. This would exceed the lower estimate of convertible land, but fall

Table 4-8. AMOUNTS OF LAND CONVERTIBLE TO CROPS IN IOWA AND THE MISSISSIPPI DELTA

	Iowa	Mississippi Delta
Crop prices, 1979 $ ($/bu.)		
Wheat	*	3.79
Corn	3.25	3.25
Soybeans	6.94	6.94
Convertible land (million acres)	.5 to 1.0	2.6
NIRAP prices, 1985 in 1979 dollars ($/bu.)		
Wheat	3.09	
Corn	3.01	
Soybeans	7.36	

Sources: Iowa from Amos; Delta from Shulstad, May, and Herrington, NIRAP prices from Table 1-3. The estimates of convertible land assume real input prices one-third above those of 1978. Other scenarios in the two studies assumed no increase in real input prices.

*Wheat was not considered in Iowa.

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well within the upper bound. Table 4-6 indicates that by 2010 the demand for cropland in the Cornbelt would exceed 1977 supply by 11 million acres, well beyond the maximum amount indicated by the Amos study as convertible. Our yield projections for feedgrains and soybeans in the Cornbelt show increases of about 30 percent each from 1985 to 2010. This would tend to increase the amount of convertible land beyond that estimated by Amos, but the outcome would be affected also by the behavior of input and conversion costs, and the effect of demand growth on crop prices. We expect prices of inputs to rise more or less steadily from 1985 to 2010, but we have no basis for projecting the amount of the increase. Nor are we able to estimate the effects of crop demand growth on crop prices.

Table 4-6 indicates that the demand for cropland in the Delta would exceed 1977 supply by .6 million acres in 1985, well under the 2.6 million acres estimated as convertible by Shulstad et al. By 2010, however, demand would exceed 1977 supply by 4.3 million acres.

In summary, it appears that if yields in the Cornbelt and Delta region grow as we have projected and real prices behave as the NIRAP model indicates, then our 1985 projections of the demand for cropland in those two regions could be met. Whether this could be true in other regions is difficult to say, since we lack detailed studies of land conversion potential in those regions.

Whether the demands for land projected for 2010 will be satisfied is even less certain. However, if real prices of inputs rise faster than crop yields, as we think likely, it is clear that real crop prices will have to rise from 1985 to 2010 to make conversion of land on the required scale profitable. Conceivably the increase in crop prices could erode the U.S. position in world markets for grains, soybeans and cotton, thus causing the demand for crop production to grow more slowly than we have projected. In this case the demand for cropland also would grow more slowly, reducing pressure to convert land now in pasture, forest, and range.

We assume that real crop prices will increase enough to justify conversion of enough land to meet the demands for cropland projected for 2010, but not so much as to reduce demand for crops significantly below the projections shown in Section 1.

Conversion to Non-agricultural Uses--

Table 4-6 indicates that by 2010 the demand for cropland would exceed 1977 supply by 64 million acres. The additional land would have to come from land now in pasture, forest, and range. However, the amount of land converted would exceed 64 million acres because some of the land now in crops, pasture, forest, and range will be converted to urban and other uses that will make it permanently unavailable as cropland. Between 1967 and 1975, about 2 million acres of land per year were so converted (Brewer and Boxley). Less than 1 million of these acres, however, were cropland or potential cropland.

If this rate of conversion continues some 25-30 million acres of cropland and potential cropland would be lost to agriculture between 1977 and 2010. In fact, however, the rate of conversion is likely to be less than that experienced in 1967-75. One of the principal factors underlying that experience was urban population growth and its continued spread into formerly rural areas. While population will continue to grow and to demand additional land in rural areas for residential purposes, the absolute rate of growth is expected to decline, which should reduce pressure on the rural land base relative to 1967-75.

Another important source of pressure on the rural land base in 1967-75 was construction of the interstate highway system. This system now is substantially completed.

Strip mining of coal likely will become more important over the next several decades in response to rising demands for energy and diminishing supplies of petroleum and natural gas. However, the amount of land used for this purpose is expected to be quite small, and not all of it will come from land now constituting the present and potential supply of cropland.[4]

Thus the annual rate of conversion to urban and similar uses of present and potential cropland is likely to be less in 1977-2010 than in 1967-75. We have no reliable way of estimating how much less, but total conversion over the thirty-three year period of 20-25 million acres is reasonable.[5]

If non-agricultural demand for present and potential cropland rises 20-25 million acres (implied by Table 4-6), then the 125 million acres of land with potential for crop production would be reduced to 41 million acres by 2010. We think it likely that conversion on this scale would increase the real economic cost of agricultural land. There are two reasons: (1) over half of the converted land would be that with medium potential, for which conversion costs are higher than for high potential land (Brewer and Boxley), (2) The conversion would reduce the supply of land in pasture, forest, and range, likely increasing the price of these lands unless land-saving technologies for use of them are developed. Pasture land in particular could be affected. The NRI shows that almost 40 percent of the land in pasture in 1977 had potential for conversion to cropland. Shulstad et al. found that in the Mississippi Delta pasture could be converted to crops more cheaply than land in other uses, and this likely is generally true. Satisfying the projected demand for cropland, therefore, probably could put greatest pressure on the supply of pasture. No doubt there is range and forest land that could be converted to pasture, but this could occur only at some cost.

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[4] Brewer and Boxley cite a study showing that by 2000 only about 1.8 million additional acres would be needed for strip-mining and siting of coal-fired power plants and associated facilities.

[5] Robert Gray, Executive Director of the federal government's National Agricultural Land Study, expects total conversion of 23-25 million acres of cropland and potential cropland from 1980 to 2000, an annual rate of 1.15 to 1.25 million acres. (Journal of Soil and Water Conservation, 1981, p. 63).

We conclude that mounting pressure on the agricultural land base is likely to increase the real economic costs of that land. We are not able to say how much these costs might rise.

Any increase, however, would raise real costs of agricultural production unless prices of non-land inputs or total productivity move to offset this. We have argued, however, that real prices of non-land inputs are likely to rise faster than productivity, in which case the effect would be to reinforce rather than offset the upward pressure of land costs on production costs. The clear implication of this set of conditions is rising real economic costs of agricultural production.

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SECTION 5

PROJECTIONS OF FERTILIZERS AND PESTICIDES

FERTILIZERS

An implication of the shift by farmers toward the land-using end of the spectrum of technologies is that fertilizer applications per acre will grow more slowly in the future than in the past. Indeed, as Table 10 in Section 2 shows, per acre applications of fertilizer grew much more slowly after 1972 than before, reflecting decreasing reliance on land-saving technologies after that date. As noted in Section 3, the slower increase in per acre applications of fertilizer after 1972 was consistent with the post-1972 slowdown in yield growth. Correspondingly, our expectation that the trend of yields to 2010 will more nearly resemble the post- than the pre-1972 experience is based in good part on our belief that per acre applications of fertilizer will grow more slowly.

Tables 5-1 and 5-2 show, respectively, amounts of fertilizer applied per fertilized acre and per harvested acre for corn, wheat, soybeans, and cotton for selected years, with projections to 1985, 1990, and 2010. The differences between the two tables, of course, reflect the percentages of harvested acres which are fertilized.

The key elements in the projections are the percentages of land fertilized and the amounts applied per fertilized acre. For corn and soybeans in 1985 and 1990 we have used projections of these elements made by Douglas.[1] We modified Douglas' projections for wheat and cotton on the basis of our judgment about recent trends. All of the projections for 2010 are by us.

Corn

Since about 1970 nitrogen fertilizer has been applied to 94 to 97 percent of corn acreage, phosphorous to 85 to 90 percent and potash to 80 to 85 percent. Our projections for 1985, 1990, and 2010 are 98 percent for nitrogen, 90 percent for phosphorous and 95 percent for potash.

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[1] Dr. John Douglas, Assistant to the Manager, Tennessee Valley Authority. Douglas' projections are in the paper listed in the references. In conversation with one of the authors in the summer of 1980 Dr. Douglas indicated he still was satisfied with his projections (they were made in 1978).

5-2

TABLE 5-1. APPLICATIONS OF FERTILIZER PER ACRE OF FERTILIZED LAND IN CORN, WHEAT, SOYBEAN AND COTTON (POUNDS)

Rate per receiving acre

	Corn			Wheat			Soybeans			Cotton		
	N	P	K	N	P	K	N	P	K	N	P	K
1965	73	47	42	31	29	13	10	28	34	77	52	34
1970	112	71	72	39	30	36	14	37	51	75	55	57
1972	115	66	69	46	37	38	14	42	51	75	55	61
1973	114	64	71	48	38	36	14	42	55	73	53	62
1974	103	62	73	46	38	37	15	41	55	78	53	55
1975	105	58	67	46	35	35	15	40	53	78	50	55
1976	127	67	78	51	37	37	14	42	60	81	52	56
1977	128	68	82	53	39	41	16	45	60	78	53	52
1978	126	68	80	52	35	34	17	45	62	76	54	54
1979	135	69	84	54	38	43	16	46	67	71	50	44
1980	130	66	86	58	39	40	17	46	70	72	46	46
1985	136	70	86	60	38	42	17	50	73	67	55	50
1990	140	70	87	65	38	43	18	53	80	65	55	50
2010	145	70	90	65	38	43	20	55	85	60	55	50

Sources: 1965-1979 from USDA 1971, Jan. 1977 and December 1980. Corn and Soybeans in 1985 and 1990 from Douglas. All other projections as described in the text.

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TABLE 5-2. APPLICATIONS OF FERTILIZER PER ACRE OF HARVESTED LAND IN CORN, WHEAT, SOYBEANS, AND COTTON (POUNDS)

	Rate per harvested acre											
	Corn			Wheat			Soybeans			Cotton		
	N	P	K	N	P	K	N	P	K	N	P	K
1965	64	38	31	15	11	2	*	3	3	60	30	14
1970	105	64	61	24	13	7	3	10	14	54	26	21
1972	110	59	59	29	16	6	3	12	16	58	30	25
1973	106	55	57	30	17	6	3	13	18	54	29	24
1974	97	54	61	30	17	7	3	11	15	62	31	25
1975	99	50	55	29	15	7	3	10	15	51	22	18
1976	123	60	66	36	19	8	3	12	14	61	28	21
1977	123	60	67	34	17	8	4	15	18	61	27	16
1978	120	59	65	32	13	5	4	16	20	52	24	17
1979	130	61	69	35	17	8	4	17	26	50	24	12
1980	125	57	70	39	17	7	4	16	25	51	22	14
1985	133	63	73	39	19	10	4	18	26	47	28	15
1990	138	63	74	46	20	10	5	20	31	42	25	14
2010	142	63	77	49	22	10	5	22	35	36	22	13

*Less than one pound.

Sources: 1965-1979 from USDA 1971, January, 1977 and December, 1980. Corn and Soybeans in 1985 and 1990 from Douglas. All other projections as described in the text.

5-4

Douglas projects very little increase in amounts of fertilizer applied per acre of corn fertilized, arguing that much if not most land in corn already is being fertilized at economically optimum rates. Heady expresses a similar view. If real fertilizer prices, particularly for nitrogen, rise as we expect, the economic optima will not likely change in the direction of heavier per acre applications of fertilizer. On the contrary, price movements likely will induce farmers to find ways to reduce fertilizer use without commensurate sacrifice of yield. There evidently already are ways of doing this which would be economically attractive with the higher fertilizer prices now in prospect.[2] Stanford (1978) believes that current yield levels can be maintained with "...an appreciable increase in efficiency" of nitrogen fertilization. He identifies three areas for improvement: more appropriate application rates, timing of application, and method of application. Stanford argues that amounts of nitrogen applied often are higher than necessary because farmers lack knowledge of the amount of soil organic nitrogen that will be made available to the plant by mineralization. Stanford is optimistic that current research will develop ways of predicting mineralization rates, thus enabling the farmer to incorporate this source of nitrogen into his plans and reduce the amount of purchased nitrogen applied.

Stanford also sees potential for greater efficiency by splitting applications of nitrogen in two parts: one application at planting to act as a "starter" to promote early plant growth, and a second "sidedressed" application during the growing season to insure adequate nutrients to harvest. The alternative is to apply all the nitrogen before or at the time of planting. The advantage of split applications is that it supplies nutrients at times more in accord with the plant's need for them over the growing season, thus reducing nutrient losses that otherwise result from soil processes working on the nutrient material. However, sidedressing involves some risk. Wet fields can delay the operation, possibly causing root damage from nitrogen deficiency, or allowing the crop to grow too high to drive the application equipment through (Aldrich, 1980). Moreover, sidedressing is more difficult and more time-consuming than pre-plant broadcasting. When anhydrous ammonia is knifed-in between the rows, special care must be taken not to prune corn roots.

Split applications of nitrogen would have the highest pay-off where leaching losses of nitrogen are greatest, such as in the sandy soils of the Southeast. In the Midwest, where nitrogen fertilizer use is greatest, split applications would be less attractive because soils in that area have high clay content and leaching losses are relatively low. However, if real prices of nitrogen fertilizer rise as we expect, split applications should become more attractive everywhere.

Stanford also sees some potential for more sparing use of nitrogen by adoption of foliar application techniques. In field experiments with soy-

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[2] This account of alternatives permitting more sparing use of fertilizers is from Hemphill (1980). See also Aldrich, 1980, especially pages 263-270.

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beans in Iowa, foliar application outperformed conventional methods. However, with corn, which receives far more nitrogen than soybeans, problems were encountered in supplying sufficient nitrogen by foliar application without causing leaf burn.

Development of new fertilizer materials also offers a way of achieving more efficient use of fertilizers. New forms of nitrogen hold the greatest promise because an average crop now takes up only about 50 percent of nitrogen applied, less than for either P or K (Fertilizer Institute, pp. 36-39). The relatively high losses of N result from nitrification, the conversion of nitrogen fertilizer by soil bacteria to nitrate. Nitrate is soluble, hence susceptible to movement beyond the reach of crop roots by water. Nitrification results in losses of N in gaseous form also. Research is underway which aims at developing nitrogen fertilizer materials which retard nitrification, thus giving the crop more opportunity to use the nutrient before it is washed out of reach or volatilized. There are three approaches to slowing nitrification which presently seem to have most promise: (1) development of materials of low solubility which release nitrogen into the soil solution relatively slowly; (2) provide a temporary barrier between the nitrogen fertilizer and the soil by coating the nitrogen with slowly decaying materials such as plastic or sulfur; (3) apply nitrification inhibitors, chemicals which kill enough of the soil bacteria responsible for nitrification to slow the process. To date these three approaches have not proved economical for general application. However, continued research, combined with further increases in real prices of nitrogen fertilizers should make them increasingly attractive, particularly in conditions where leaching and volatilization losses of nitrogen are high.

Relatively greater use of so-called organic farming is a similar likely response to rising prices of nitrogen fertilizer. Organic farmers substitute animal manure and crop rotations which include a legume for inorganic fertilizer to supply crop requirements for nitrogen. Since corn receives far more nitrogen fertilizer than any other crop in the United States (about 40 percent of total applied N) the significance of organic farming with respect to use of nitrogen fertilizer depends largely on its potential use in corn production. Many farmers in the United States already practice organic farming, and according to a USDA report (July 1980) the technology has promise for more widespread use, particularly if real prices of nitrogen fertilizer rise. There is nothing in the report, however, to suggest that organic farming is likely to substitute in a major way for current fertilizer management practices. The USDA report examined the economics of organic and conventional farming in the Midwest using crop budget data developed by the USDA and Oklahoma State University. Three organic farming systems were examined: a four year alfalfa-corn-soybean-oats rotation; a five year alfalfa-alfalfa-corn-soybean-oats rotation; and seven year alfalfa-alfalfa-corn-soybean-corn-soybean-alfalfa rotation. The conventional system was a two year corn-soybean rotation. The conventional system produced a larger annual return above variable costs than any of the organic systems. A main reason for this was that with the organic farming systems only about 57 percent of total crop acreage on average was in corn and soybeans, while the conventional system had 100 percent of its acreage in these relatively high valued crops.[3]

The USDA report concludes that the spread of organic farming is limited by "...the lack of an adequate and economical supply of organic wastes and residues and/or because soil nutrients and climatic conditions are not suitable for successful and profitable organic farming. Based on our observations, the greatest opportunity for organic farming will probably be on small farms and on larger mixed crop/livestock farms with large numbers of animal units" (USDA, July 1980, pp. 46-47).

A large scale shift to organic farming would have a major impact on cropping patterns and land use. Meeting our crop production projections would require substantially more cropland than we have projected because the percentage of land in those crops would be substantially less in an average year. Meeting our projections with organic farming systems thus would put far more pressure on the nation's land base, implying higher land costs and costs of crop production than are implicit in our projections. In fact, however, our projections probably could not be met if there were a major shift to organic farming systems. The USDA study examined the macro-economic effects of such a shift in 1980, and found that corn and soybean prices would have been significantly higher, while oats, hay and livestock prices would have been lower. The higher corn and soybean prices would reduce the volume of exports of these commodities, although the value of exports would be higher because foreign demand for these crops is inelastic. Average costs of farm production would have been higher, with consequent higher prices of food to consumers. Farm income would be higher, indicating that a major consequence of a large scale shift to organic farming in the United States would be a redistribution of income to American farmers from U.S. and foreign consumers of food.

Lockeretz, Shearer and Kohl (1981) compared organic and conventional farms in the Cornbelt over the 5 years 1974-1978. They explicitly did not address the macro-economic implications of a large scale shift to organic farming. Between the two groups of farms compared they found that conventional farms generally had higher yields and gross revenues. However, variable costs also were higher on the conventional farms so their advantage in net revenues was small--only 2 percent over the 5 years as a whole. This is a smaller difference than was found in the USDA study. A main reason, evidently, is that many of the conventional farms studied by Lockeretz et. al. were mixed crop-animal enterprises. These farms typically have some land in relatively low value forage crops. As noted above, the USDA study assumed a corn-soybean rotation.

We conclude that the economics of organic farming do not favor a large scale shift to such systems, and that the macro-economic implications of

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[3] The study assumed that yields were 10 percent lower with the organic systems. Even if no difference in yields were assumed, however, returns above variable costs still would have been higher with the conventional system.

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such a shift would inhibit development of political support for it. Accordingly, we view the prospects for organic farming as sufficiently good to restrain the increase in per acre application of nitrogen fertilizer, but not so good as to cause a decline.[4]

Wheat

The percentage of wheat land fertilized is substantially less than that for corn, and has shown no trend in the 1970s. Sixty to 65 percent of wheat acreage receives nitrogen, 40 to 50 percent receives phosphorous and 15 to 20 percent receives potash. Douglas projects an increase in all these percentages, particularly for nitrogen. The rationale for this is not clear, and we believe the outlook for fertilizer prices makes it doubtful. Accordingly, we have projected a more modest increase in the percentages of wheat land fertilized.

Applications of nitrogen per acre of wheat land fertilized rose in the 1970s, and we project a continuation, although at a slower rate than Douglas. Phosphorous applications, however, showed no trend and that for potash was only slightly rising. Our projections of phosphorous and potash applications per acre of wheat land receiving these nutrients reflect these patterns.

Soybeans

As a legume soybeans biologically fix most of the nitrogen they require. Consequently, the percentage of soybean acreage receiving nitrogen fertilizer and the per acre amount applied to that which does are both small. Considerably greater quantities of P and K are applied to soybean land which receives any of these materials, and application rates, particularly of K, rose in the 1970s. Douglas projects a continuation of these increases. However, the percentages of soybean land which receives P and K is small, and Douglas projects little increase in it. Consequently, the projected amounts of P and K per acre of land in soybeans are small and show little increase. Douglas argues that this pattern will characterize fertilizer use on soybeans absent a significant breakthrough in the agronomics of soybean production.

Cotton

The percentage of cotton acres receiving N, P and K declined slightly in the 1970s, and the amounts applied per receiving acre were stable to slightly declining. This behavior reflected the shift of cotton acreage to the Southern Plains--Texas and Oklahoma--where percentages of acres receiving and amounts per receiving acre are low, from the Southeast and Mississippi Delta, where percentages and amounts are high. Our projections of the regional distribution of cotton production and acreage assume that the shift to the Southern Plains will continue. Our projections of fertilizer use are generally consistent with this shift.

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[4] According to the USDA report, organic farming may deplete soil stocks of phosphorous and potash, indicating that after a few years of organic farming, these nutrients would have to be applied on a regular basis. Adoption of organic farming, therefore, particularly on the modest scale we anticipate, would not restrain per acre applications of P and K.

Other Uses of Fertilizer

In addition to its use on corn, wheat, soybeans and cotton, fertilizer also is applied to other field crops, hay and pasture, fruits and vegetables, forests, home gardens and lawns, golf courses, roadways and for other miscellaneous uses (Douglas). In the second half of the 1970s these other uses took about 43 percent of all the nitrogen applied, 39 percent of the phosphorous and about 42 percent of the potash. Douglas' projections indicate that the percentage of nitrogen taken by these other uses would rise to 50 percent in 1985 and to 52 percent in 1990. For P and K Douglas projects only marginal increases in the percentages taken by these other uses.

We think it likely that the price elasticity of demand for these other uses of fertilizer is lower than it is for corn, wheat, soybeans and cotton. The average homeowner, for example, is likely to be less sensitive to the price of fertilizer in deciding how much to apply to his garden or lawn than the farmer in deciding how much to apply to his corn crop. Douglas' projections for the four main crops are consistent with this line of reasoning. We project the amounts of N, P and K taken by other uses by assuming that they will be in the same relation to our projected amounts of each used on the main crops as in Douglas' projections. Table 5-3 shows the projections for each crop and for all other uses.

PESTICIDES

Data Problems

Projections of pesticide use are on an uncertain footing because of wide and unexplained discrepancies among the data showing present amounts used and trends in amounts. Perhaps the most widely cited data are from surveys of pesticide use conducted by the USDA in 1966, 1971 and 1976. These data, however, are at variance with those collected by others. This is indicated in Table 5-4. Von Rumker et. al. carefully examined the differences between their estimates and those of the USDA. They concluded that some of the differences could be accounted for by increased use from 1971 to 1972, e.g., methyl parathion and toxaphene on cotton and soybeans; also alachlor. The greater part of the differences, however, could not be explained in this way. Von Rumker et. al. note that the USDA estimates are from a survey using a "...mammoth form consisting of 56 pages and 487 questions..." (page 27) which required approximately 3 hours to complete. Twenty-eight of the 487 master questions had to do with pesticides. According to von Rumker et. al. even a person highly trained in the field of pesti-

TABLE 5-3. AMOUNTS OF FERTILIZER APPLIED TO LAND IN CORN, WHEAT, SOYBEANS, COTTON AND FOR ALL OTHER USES (MILLIONS METRIC TONS)

	1977/79			1985			2010		
	N	P	K	N	P	K	N	P	K
Corn	3.97	1.93	2.15	4.83	2.29	2.65	5.96	2.64	3.24
Wheat	.87	.41	.18	1.32	.64	.34	2.01	.90	.41
Soybeans	.10	.30	.61	.13	.58	.83	.25	1.09	1.73
Cotton	.31	.16	.08	.30	.18	.10	.25	.15	.09
Total of 4	5.25	2.80	3.02	6.58	3.69	3.92	8.47	4.78	5.47
All Other	4.18	2.11	2.28	6.58	2.67	3.08	9.18	3.46	4.48
Total	9.43	4.91	5.30	13.16	6.36	7.00	17.65	8.24	9.95

Source: 1977/79 from USDA, December 1980. Projections as described in text.

cides, with knowledge of the many different kinds and formulations of materials used, would have difficulty completing the form accurately.

The estimates of von Rumker *et. al.* are based on comprehensive surveys of agricultural extension specialists in the various states, directors of EPA community pesticides studies projects in a number of states, and pesticide manufacturers. For 25 most important pesticides which they studied intensively von Rumker *et. al.* concluded that their estimates were accurate within ± 10 percent for quantities over 10 million pounds and generally within ± 1 million pounds for quantities less than 10 pounds.

Von Rumker *et. al.* conclude that their estimates are more accurate than those of the USDA, and we accept this judgment. However, the USDA estimates have the major advantage of covering several years (1964, 1966, 1971 and 1976), thus providing information about changes over time. This information of course is particularly valuable in making judgments about trends in future use of pesticides.

We resolved the dilemma posed by differences in the pesticide use data by rejecting projections of specific quantities of various kinds of pesticides. Instead we project directions of change, and marshal evidence for judgments of whether the changes are likely to be much or little. For this purpose we believe the USDA data are adequate and useful, especially since they were collected on a consistent basis, even though the totals for each year may be questionable. We focus only on insecticides and herbicides

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TABLE 5-4. CONTRASTING ESTIMATES OF AMOUNTS OF HERBICIDES AND INSECTICIDES USED IN THE UNITED STATES (MILLIONS POUNDS ACTIVE INGREDIENTS)

	(1) von Rumker *et al* (1972)	(2) USDA (1971)	(3) Col. (1) ÷ Col. (2)
Insecticides			
Carbaryl	19.0	11.2	1.70
Carbofuran	5.0	2.8	1.79
Disulfoton	4.9	2.8	1.75
Methyl parathion	39.7	27.1	1.46
Parathion	10.0	7.0	1.43
Toxaphene	57.0	31.9	1.79
Total	135.6	82.8	1.64
Herbicides			
Alachlor	21.0	14.0	1.50
Atrazine	72.0	53.9	1.34
2,4-D	36.0	30.5	1.18
Trifluralin	16.8	10.3	1.63
Total	145.8	108.7	1.34
Insecticides on Cotton	105.0 (approx.)	73.4	1.43

Sources: von Rumker *et al* 1975; USDA from Andrilenas, 1974.

used in crop production.[5]

Insecticides

Tables 5-5 through 5-9 show data on insecticides used on crops. For our purposes the most important information in the tables is the following:

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[5] Fungicides and other pesticides accounted for 14 percent of the quantity of all pesticides used on crops in 1976, down from 19 percent in 1971. The share of these materials among all pesticides used on crops of interest to this study is much less than these percentages indicate. Moreover, these materials in general pose fewer threats to the environment than insecticides and herbicides.

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TABLE 5-5. PESTICIDE USE ON CROPS IN 1971 AND 1976

	Amounts applied (millions lbs. active ingredients)		Acres treated (millions)	
	1971	1976	1971	1976
Herbicides	224.0	394.3	157.8	196.6
Insecticides	153.8	162.1	56.7	74.9
Fungicides	39.6	43.2	8.5	10.5
Other	46.3	50.2	10.0	11.6
Total	463.7	649.8	n.a.	n.a.

Source: Eichers, Andrilenas and Anderson, 1978, p. 6.

n.a. = not available

TABLE 5-6. PERCENTAGES OF ACRES ON WHICH PESTICIDES WERE USED IN 1976, MAJOR CROPS

9-1/8"

	Herbicides	Insecticides	Fungicides	Other pesticides	Any pesticides
Corn	90	38	1	1	92
Cotton	84	60	9	34	95
Wheat	38	14	1	*	48
Sorghum	51	27	-	*	58
Other grains†	35	5	2	-	41
Soybeans	88	7	3	1	90

Source: Eichers, Andrilenas and Anderson, 1978, p. 7.

*Less than .5 percent

†Oats, rye and barley

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TABLE 5-7. HERBICIDES AND INSECTICIDES APPLIED TO MAJOR CROPS IN 1971 AND 1976 (ACTIVE INGREDIENTS)

	Herbicides				Insecticides			
	1971 Amount		1976 Amount		1971 Amount		1976 Amount	
	Total (mill. lbs)	Per Acre Treated (lbs)	Total (mill. lbs)	Per Acre Treated (lbs)	Total (mill. lbs)	Per Acre Treated (lbs)	Total (mill. lbs)	Per Acre Treated (lbs)
Corn	101.1	1.7	207.1	2.7	25.5	1.2	32.0	1.0
Cotton	19.6	1.9	18.3	1.9	73.4	9.8	64.1	9.2
Wheat	11.6	.5	21.9	.7	1.7	.4	7.2	.6
Sorghum	11.5	1.2	15.7	1.7	5.7	.7	4.6	.9
Other grains	5.4	.5	5.5	.5	.8	.7	1.8	1.2
Soybeans	36.5	1.2	81.1	1.8	5.6	1.6	7.9	2.3
Total of these crops	185.7	n.a.	349.6	n.a.	112.7	n.a.	117.6	n.a.
Total all crops	224.0	1.4	394.3	2.0	153.8	2.7	162.1	2.2

Source: Eichers, Andrilenas, and Anderson, 1978, pp. 9 and 15.

*Oats, rye, and barley.

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TABLE 5-8. TYPES AND AMOUNTS OF INSECTICIDES APPLIED TO MAJOR CROPS IN 1976

	Millions lbs	Percent of total
Corn		
Carbofuran	9.9	30.9
Phorate	5.8	18.1
Fonofos	5.0	15.6
Other	11.3	35.4
Total	32.0	100.0
Cotton		
Toxaphene	26.3	41.0
Methyl parathion	20.0	31.2
Other	17.8	27.8
Total	64.1	100.0
Wheat		
Parathion	3.1	43.1
Disulfoton	1.8	25.0
Methyl parathion	1.2	16.7
Other	1.1	15.2
Total	7.2	100.0
Soybeans		
Carbaryl	3.7	46.8
Toxaphene	2.2	27.9
Other	2.0	25.3
Total	7.9	100.0
Sorghum		
Parathion	1.2	26.1
Disulfoton	1.1	23.9
Toxaphene	1.0	21.7
Other	1.3	28.3
Total	4.6	100.0

Source: Eichers, Andrilenas and Anderson, 1978, p. 18.

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TABLE 5-9. HERBICIDES AND INSECTICIDES APPLIED TO MAIN CROPS, BY REGION IN 1976 (MILLION LBS.)

	Corn		Cotton		Wheat		Soybeans		Sorghum	
	Herbicides	Insecticides	Herbicides	Insecticides	Herbicides	Insecticides	Herbicides	Insecticides	Herbicides	Insecticides
Northeast	10.93	1.02	--	--	.01	.02	1.32	.35	.13	--
Appalachian	19.09	.94	.75	4.09	.08	.17	8.21	.87	1.50	--
Southeast	8.13	.97	1.04	20.58	--	--	6.37	6.18	.05	.10
Delta	.39	.02	11.56	32.65	.06	--	15.24	.17	.42	.49
Lake	33.91	5.00	--	--	2.41	.01	6.05	.02	.02	--
Corn Belt	108.04	14.09	--	--	.06	.48	41.51	.12	1.30	.30
Northern Plains	22.81	8.17	--	--	6.22	.40	2.35	*	7.94	2.20
Southern Plains	1.66	1.25	2.76	2.46	.98	4.49	.01	.15	4.10	1.37
Mountain	1.19	.37	1.30	3.34	3.92	.41	--	--	.22	.06
Pacific	.91	.14	.90	1.02	8.15	1.27	--	--	.05	.09
U.S.	207.06	31.98	18.31	64.14	21.88	7.24	81.06	7.87	15.72	4.60

Source: Eichers, Andrilenas and Anderson, 1978, pp. 13 and 19.

*Less than 5000 pounds.

TABLE 5-10. TYPES AND AMOUNTS OF HERBICIDES APPLIED TO MAJOR CROPS IN 1976

	Millions lbs	Percent of total
Corn		
Atrazine	83.8	40.5
Alachlor	58.2	28.1
Butylute	24.3	11.7
Other	40.8	19.7
Total	207.1	100.0
Cotton		
Trifluralin	7.0	38.3
Flurometuron	5.3	29.0
Other	6.0	32.7
Total	18.3	100.0
Wheat		
2, 4-D	15.5	70.8
Other	6.4	29.2
Total	21.9	100.0
Soybeans		
Alachlor	29.6	36.5
Trifluralin	21.1	26.0
Other	30.4	37.5
Total	81.1	100.0
Sorghum		
Atrazine	6.5	41.4
Propazine	3.9	24.8
Propachlor	3.1	19.8
Other	2.2	14.0
Total	15.7	100.0
Other grain*		
2, 4-D	3.8	69.1
Other	1.7	30.9
Total	5.5	100.0

*Oats, rye and barley.

Source: Eichers, Andrilenas and Anderson, 1978, p. 12.

1. The total amount of insecticides applied increased 5.4 percent from 1971 to 1976, much less than the percentage increase in quantity of herbicides.

2. Insecticides applied to cotton accounted for 48 percent of total crop use of insecticides in 1971 and for 40 percent in 1976.

3. Corn accounted for 17 percent of total crop use of insecticides in 1971 and for 20 percent in 1976.

4. In 1976 83 percent of the insecticides applied to cotton was used in the Mississippi Delta (50.9 percent) and the Southeast (32.1 percent). Together, these two regions accounted for one-third of all the insecticides used on crops in the entire nation.

5. The Cornbelt, Northern Plains and Lake States accounted, respectively, for 44.1 percent 25.5 percent and 15.6 percent of all insecticides applied to corn in 1976.

6. Amounts of insecticides applied per acre of land in cotton and corn declined from 1971 to 1976.

7. Organochlorine compounds (e.g. DDT, toxaphene) declined from 46 percent of all insecticides applied to crops in 1971 to 29 percent in 1976. Organophosphorus compounds (e.g. methyl parathion) increased from 40 to 49 percent and carbamates (e.g. carbaryl, carbofuran) increased from 14 percent to 19 percent.[6]

These statements suggest that unless there is reason to believe that insecticides will be applied to sharply higher percentages of land in wheat and soybeans, the direction of total insecticide use on crops in the future will depend overwhelmingly on trends in use on cotton in the Southeast and Delta and on corn in the three principal corn producing regions. Further, if the substitution of organophosphorous for organochlorine compounds continues, problems resulting from persistence of insecticides in the environment will diminish in relative importance and those of acute toxic effects on humans and animals will increase.

Wheat--

The percentage of wheat acres treated with insecticides and the amount applied per treated acre are small (Tables 5-6 and 5-7) because wheat generally is not attacked by insects on a scale requiring a response. The principal insect pests of wheat are the Hessian fly, greenbug, wheat stem sawfly, armyworms and cutworms (Office of Technology Assessment, OTA). According to the OTA, these pests present "serious to occasional" threats to wheat. However, the damages typically are sufficiently small that it is not economical for farmers to invest heavily in insecticide treatments. By 1971 95 percent of the insecticides used on wheat were organophosphorous compounds (OTA, p. 21). Use of cultivars with resistance to insects is a major control practice in wheat production. According to the OTA (p. 27) it is in fact the most effective means for controlling the Hessian fly and wheat stem sawfly.

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[6] These data are not in Tables 5-5 through 5-9. They are from Eichers, Andrilenas and Anderson, 1978, page 16.

In judging the development of control strategies for wheat insects into the 1990s the OTA concludes that the role of insecticides likely will diminish. It is expected that more accurate determination of economic thresholds will reduce unneeded applications and improvements in application equipment will result in desired levels of control with smaller amounts of insecticides.

The OTA report thus gives no reason to believe that the percentage of wheat acres treated with insecticides or the amounts applied per treated acre are likely to increase. On the contrary, the thrust of the argument in the report is that insecticide use on wheat is likely to decline. In this connection we think it significant that in a major study by the National Academy of Sciences of pesticide practices in the United States separate volumes were prepared dealing with cotton and with corn/soybeans, but none with wheat. The EPA commissioned a study of alternatives for reducing insecticides applied to cotton and corn (Pimentel et. al.) but evidently has seen no need for a similar study for wheat.

We have projected harvested wheat land at 90 million acres in 2010, compared with 70.8 million acres in 1976, the year to which the USDA's insecticide use data apply. If the percentage of wheat land receiving insecticides and the amount per receiving acre in 2010 are the same as in 1976, 9.2 million pounds of these materials would be applied in 2010, up from 7.2 million pounds in 1976 (Table 5-7). If the OTA is right in thinking that insecticide per acre usage on wheat will decline, the increase from 1976, of course, would be less.

Soybeans--

The low percentage of soybean land treated with insecticides (Table 5-6) masks a wide difference between the percentages for soybean land in the Cornbelt and Delta on the one hand and in the Southeast on the other. According to the OTA report 1 to 10 percent of soybean land in the Cornbelt is treated annually for insects. In Arkansas the figure in 1977 was 6 percent and in Louisiana and Mississippi 90 percent and 75 percent respectively. However, the report notes that the figures for Louisiana and Mississippi "were very high compared with normal usage." In the Southeast the percentage of soybean land treated was 70-75 percent, which evidently is typical for that region.

In 1977/79 the Southeast had 8.5 percent of the nation's land in soybeans. Our projections of production and land use imply that the Southeast's share of soybean land would rise to about 13 percent by 2010. The Delta's share also would rise somewhat and that of the Cornbelt would decline. These regional shifts in land in soybeans would imply a small increase in the nationwide percentage of soybean land receiving insecticides, assuming persistence of the regional differences in percentages noted above.

According to the OTA report there currently are only 2 major insect pests of soybeans in the Cornbelt, the Mexican bean beetle and the green cloverworm. Each now presents a "moderate" threat. By the 1990s the OTA report judges that the Mexican bean beetle may constitute a "high" threat, but that the threat from the green cloverworm would remain moderate. The threats from all other insect pests of soybean pests in the Cornbelt are judged now to be low to very low, and to remain that way into the 1990s. The OTA report has little to say concerning future practices for control of soybean insect pests in the Cornbelt. It notes, however, that insect-tolerant varieties of soybeans have been identified and a strong effort is underway to introduce this characteristic into commercial varieties of soybeans. According to the report, total resistance is not necessary for soybeans in the Cornbelt. Varieties with 50-75 percent tolerance to leaf-feeding caterpillars and beetles would have little need for insecticides.

The high percentage of soybean land in the Southeast which receives insecticides indicates that the insect problem in that region is more severe than in the Cornbelt or Delta. The OTA report concludes that insecticides will continue to play a role in control of insect pests of soybeans in the Southeast and in the Delta. The report notes, however, that varieties with resistance to soybean insects of those regions already have been developed and asserts that a much greater commitment of resources to research along this line would have high pay-off over the long term. The report also sees promise in the present development of biological techniques for control of soybean insects in the Southeast and Delta, and urges that further development of these techniques should receive high priority.

In summary, although the small relative shift of soybean production to the Southeast would tend to increase slightly the nationwide percentage of soybean land receiving insecticides, the development of alternative control practices in the Southeast, Delta, and Cornbelt looks promising enough to offset this tendency. Unless there is an outbreak of some insect pest of soybeans not presently identified as a serious threat, it appears unlikely that the percentage of soybean acreage receiving insecticides or the amounts applied per receiving acre will increase much, if at all. If the percentage and amounts per acre remain the same, our projection of land in soybeans would imply an increase in insecticides used on soybeans from 7.9 million pounds in 1976 (Table 5-7) to 17.4 million pounds in 2010.

Corn--

The principal insect pests of corn are the northern and western rootworm, European cornborers and the black cutworm (OTA 1980). Of these, the corn rootworm is easily the most important, and most of the insecticides applied to corn are for control of this insect. It is not too much to say that the future trend in use of insecticides on corn will depend primarily on development of practices which modify or substitute for insecticides currently used to control the rootworm.

At present the principal alternative to insecticides for control of the corn rootworm is rotation with another crop, primarily soybeans, since the rootworm must have corn roots to survive. In deciding whether to adopt this practice the farmer, of course, will consider and balance the economics of the corn-soybean rotation against its advantages for control of the rootworm. According to a study of Miranowski (1979) the corn-soybean rotation, with no use of insecticides, was in fact the most economical means of controlling the corn rootworm in the Cornbelt under cost-price relationships prevailing in the late 1970s.

Part of the advantage of control by rotation is that it slows the buildup of genetic resistance of the rootworm to insecticides, thus extending the useful economic life of currently used chemicals. This advantage likely will increase in the future because of increasing costs of developing new insecticides (OTA, Part 3, p. 43).

So-called insect monitoring programs, or "scouting" are coming into increasing use for control of insect pests of corn. Scouting is the key component of so-called integrated pest management (IPM) in corn. The principle of IPM as currently practiced is to apply insecticides only when, where and in the amount needed to prevent insect pest damage from crossing the economic threshold. The programs rely on "scouts" to provide information about the number of insects in the field and about the threat they present at various stages of their life cycle and that of the plant. Typically these programs result in more sparing use of insecticides for a given level of insect control than practices based on rules-of-thumb about when and how much insecticide to apply. In effect, IPM substitutes knowledge at the margin for chemicals to control insects.

Limited or experimental scouting programs have been mounted by the Agricultural Extension Service in the Cornbelt and have been well received by farmers. The spread of these programs could significantly reduce the quantities of insecticides needed for effective control of the corn rootworm (OTA, Part 3, pp. 37-38).[7]

The development of cultivars of corn with greater insect resistance than those now used also has good potential as an insect control strategy. The OTA expects that this strategy in fact will pay-off by the 1990s, resulting in a reduction from 1976 levels in the amount of insecticides applied to corn (OTA, Part 3, p. 51).

We expect a considerable expansion of corn land in conservation tillage, for reasons detailed below in the discussion of herbicides. Accord-

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[7] David Pimental (personal communication) is less sanguine than the OTA about the potential for scouting to reduce insecticide use on corn. He points out that only about one pound of active ingredient is used per acre, indicating that the cost of treatment is low.

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ing to the OTA report this could increase the threat to corn of insects now only of minor importance. Conservation tillage leaves residue from the previous crop on the soil surface, creating a hospitable environment for insects, particularly the black cutworm and armyworm, which could not flourish in a clean tilled field. To the extent that this occurs, it would offset the effects of increased corn-soybean rotation and scouting in reducing the amount of insecticides applied to corn. It is worth noting in this connection, however, that the amount of land in conservation tillage doubled between 1972 and 1976 (No-Till Farmer, March 1979) but total insecticide use increased less than 6 percent (Table 5-5). If conservation tillage required significantly more insecticides than conventional tillage one would have expected insecticide use to increase more. Conservation tillage definitely requires more herbicides than conventional tillage, and harbicide use rose sharply from 1971 to 1976 (Table 5-5).

Our projection of land in corn indicates a 30 percent increase from 71.3 million acres in 1976 to 93 million acres in 2010. We expect a decline in the amount of insecticides applied per receiving acre of corn, or in the percentage of land receiving insecticides, or in some combination of the two, to more than offset the increase in land in corn.[8] Accordingly, we expect the total amount of insecticides applied to corn to decline over the next several decades.

Cotton--

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We expect a significant decline from 1976 to 2010 in the total amount of insecticides applied to cotton. There are two reasons: (1) a marked shift in the regional distribution of land in cotton from the Mississippi Delta, where rates per receiving acre are high, to Texas where rates per receiving acre are low; (2) a decline in present high rates per receiving acre in the Delta and in the Southeast.

Because the climate in the High Plains of Texas is hostile to cotton insect pests, cotton farmers in that region can produce a crop in most years without applying any insecticides (National Academy of Sciences 1975). Since 40-45 percent of the cotton acreage in Texas is in the High Plains, the low per acre amounts of insecticides applied in that area keep the average amount for the state as a whole low.

But application rates elsewhere in Texas also are low in comparison with rates in the Southeast and Delta. The reasons for this are complex, and what follows does not pretend to be a complete account. There appear to be two key components to the explanation, however. One is that beginning in the 1950s the key insect pests of cotton in Texas began to develop gene-

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[8] According to Table 5-7 a decline in the amount of insecticides per receiving acre of corn already had occurred from 1971 to 1976.

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tic resistance to insecticides.[9] First the boll weevil, then the cotton fleahopper and thrips, became effectively immune to DDT and other organochlorine compounds. Subsequently, the cotton bollworm and tobacco budworm also developed resistance to these materials. Farmers switched to organophosphorous compounds, at first with good success, but subsequently the tobacco budworm developed resistance to these as well. The result was that when farmers sprayed with organophosphates to control the boll weevil or other primary insect pests, they also killed off predators of the budworm, which then was able to, and often did, wreak considerable damage.

Researchers went to work on this problem and came up with insect management practices which usually give adequate control with relatively little reliance on insecticides. These practices are built around the fact that in most instances the tobacco budworm is a secondary pest of cotton whose numbers can be kept below economically damaging amounts by reliance on insect predators of the budworm. The key is not to destroy the predators. This is avoided by spraying either very early in the cotton growing season with one or two treatments to kill boll weevils surviving the winter or for fleahopper infestation, or very late in the season to get weevils preparing to overwinter. These approaches avoid outbreaks of the budworm-bollworm complex so well that multiapplications of insecticides no longer are needed or considered good practice by most cotton producers in Texas.

This mode of attack has benefited also from the development and adoption of "short-season" varieties of cotton in Texas. These varieties mature earlier than the varieties they have replaced, getting them through the stage of development when they are most vulnerable to insect attack before insect populations swell to threatening numbers.

The other major component to the explanation of why per acre applications of insecticides to cotton are relatively low in Texas is that the yield potential of cotton land in the state is less than in the Delta and Southeast (National Academy of Sciences 1975, p. 65). Consequently, the yield increase that Texas cotton farmers would obtain if they put on as much insecticides as farmers in the Delta and Southeast would not justify the additional cost. Moreover, cotton in the Southeast and Delta encounters stronger competition than in Texas from other high value crops, e.g., soybeans. To meet the competition farmers in those regions must get higher cotton yields than in Texas, which implies higher per acre use of insecticides.[10]

In 1976 .51 pounds of insecticides were applied per acre of cotton in Texas and Oklahoma. The figures were 10.96 pounds in the Delta and 24.92

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[9] This account of developing insect resistance to insecticides is based on OTA, Part 8, and on conversations with Ray Frisbie, Michael McWhorter, Robert Metzer and Knox Walker, all of Texas A&M University.

[10] Cotton yields in Texas averaged 345 pounds per acre in 1977/79. In the Delta they were 566 pounds and in the Southeast 482 pounds (USDA, January 15, 1980.

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pounds in the Southeast.[11] The average application rate for the three regions was 6.44 pounds per acre. Our projections of the regional distribution of land in cotton would reduce this average to 4.06 pounds in 1985 and to 3.29 pounds in 2010, even if per acre applications in each region remained at the 1976 level. In this case the amounts of insecticides used on cotton in the three regions would decline from 55.7 million pounds in 1976 to 45.3 million pounds in 1985 and 38.8 million pounds in 2010.[12]

Per acre applications of insecticides to cotton in Texas already are so low that they probably will not go much lower. They could rise if the boll weevil or other primary pests were to develop resistance to the organophosphorous compounds now used, requiring increased applications for a given amount of control. This ultimately would be a self-defeating response, however. And the demonstrated capacity of the research establishment and cotton producers in Texas to develop insect control strategies requiring only sparing use of insecticides suggests they would not respond to increasing boll weevil resistance simply by increasing per acre application rates. On this ground we think it unlikely that rates will rise much if at all in Texas. Even if they do increase somewhat, they are so low relative to those in the Southeast and the Delta that the projected shift of cotton acreage to Texas still would reduce the average application rate and total amount of insecticides used on cotton in the three regions.

As noted above, the higher yield potential of cotton land in the Southeast and Delta compared to Texas makes it economical for farmers in those two regions to apply more insecticides per acre than Texas farmers do. This suggests that per acre applications in the Southeast and Delta will continue to be well above rates in Texas for the foreseeable future. Nonetheless, there is reason to believe that they will decline from the 1976 rates. Indeed, some observers believe they already have, at least in some places.[13] Where amounts applied per acre have declined the increased use of synthetic pyrethroids is one of the reasons. This material, effective against the budworm-bollworm complex where other insecticides are not, is applied in much smaller amounts than the material it replaces. However, according to

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[11] Total insecticides applied in each region are from Eichers, Andrilenas and Anderson. Land in cotton is from USDA 1979,

[12] At the beginning of this discussion of pesticides it was noted that the USDA estimates of use differ significantly from others and are probably too low. This would not likely affect the proportionate distribution of use among regions, however. Consequently, while the above estimates of per acre insecticide use on cotton in each region may be too low, estimates of the effect of a shift to the Southern Plains on the average application rate for the three regions should accurate enough.

[13] In conversation with one of the authors in the winter of 1980, James Hamer, Agricultural Extension specialist at Mississippi State University involved in cotton pest management programs, stated that insecticide use on cotton in Mississippi probably had declined from the 1976 level.

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Hamer (see footnote 13) the apparent decline after 1976 in pounds of insecticides applied to cotton in Mississippi was not just because of the increased use of pyrethroids.

Cotton farmers in the Delta and Southeast have rapidly increased the use of cotton pest management consultants in the last few years. According to Hamer these consultants now provide pest management services to operators of about 85 percent or 730,000 to 750,000 acres of cotton land in the Delta region of Mississippi. About 75 percent of cotton acreage in Alabama is said to be scouted for insects by extension trained people and about 18 percent by professional consultants.[14] Most farmers in South Carolina use scouts, according to one source, and in Georgia about 85 percent of cotton acreage is scouted, according to another.[15] While data are not available showing the effects of the spread of scouting on insecticide application rates, the presumption is that rates required for a given amount of protection decline. As pointed out in the discussion of IPM in corn, scouting involves substitution at the margin of knowledge for insecticides.

As noted above, one of the key components of cotton insect management strategies in Texas is use of "short-season", or early maturing varieties, the advantage of these varieties being that they pass through the stages of greatest vulnerability to insect attack before insect populations reach threatening size. It is natural to ask whether these varieties could not also be used in the Delta and Southeast to reduce requirements for insecticides.

Research is under way to develop short-season varieties adapted to those regions. Some are now used in Mississippi but the acreage is very small. There are some important obstacles to widespread adoption of these varieties, however. The Texas varieties were developed for use in a dry climate, a condition not met in the Delta and Southeast. Not only is the climate wetter in those regions, but it also is less predictable. The traditional, long-season varieties used in the Delta and Southeast are more resilient in recovering from unexpected weather stress than the short-season varieties of Texas. Where the short-season varieties have been tried in experiment stations in the Southeast yields have been lower than with the traditional varieties. This is not a serious disadvantage in Texas where total costs per acre generally are lower than in the Southeast, but in the latter region high yields are necessary to offset higher costs. Finally, in the Southeast and parts of the Delta the spring is colder than in south Texas, which delays planting, thus negating some of the advantage of the

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[14] Communication with John French, pest management specialist with the Cooperative Extension Service, Auburn University.

[15] Communication with Donald Johnson, Department of Entomology and Zoology, Clemson University, and with William Lambert, Coastal Plain Experiment Station, Tifton, Georgia.

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short-season varieties.[16]

The USDA is sponsoring research on three approaches to management of cotton insect pests: boll weevil eradication (BWE), optimum pest management (OPM), and current insect control (CIC) practices. The objective is to describe relevant features of the alternative approaches and estimate their economic and environmental impacts, both at the farm level and throughout the cotton belt. The studies are expected to serve as a basis for choosing among insect management strategies and for policies to promote the chosen strategies, or mix of strategies. Since the results of the studies are not available at this writing it is impossible to know what their implications may be with respect to trends in quantities of insecticides applied to cotton. At least one participant in the studies, however, asserts that the main difference between the OPM strategy and the CIC strategy is that OPM would increase the role of knowledge about plant-insect interactions and reduce the role of insecticides, primarily because the rising costs of the latter make it imperative to use them more sparingly.[17]

There is much other research underway, most of it pointed toward finding alternatives to insecticides for insect control, alternatives which would not likely eliminate the use of insecticides, but which would diminish their role. One approach now receiving attention is development of insect resistant varieties. A variety with some resistance to the boll weevil, tobacco budworm, and fleahopper already has been developed in Texas.[18] Some use has been made of bacteria and viruses for control of the budworm complex in the Delta, although not in the Southeast, and research is continuing along these lines.[19]

While some of the various alternative strategies now being explored through research probably will not prove economically viable at the farm level, others almost surely will. Indeed, as just noted, some already have. We believe this outcome is sufficiently likely to justify the conclusion that per acre applications of insecticides to cotton in the Southeast and Delta will decline from 1976 levels, probably substantially by 2010. Since we project a reduction in total cotton acreage in those regions, we expect the total insecticide load also to decline. When this is combined with the projected shift of cotton acreage to Texas, the implication is a substantial drop for the three regions combined both in per acre applications of insecticides to cotton and in the total quantity of insecticides used.

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[16] This account of obstacles to the adoption of short-season cotton varieties in the Delta and Southeast is based on discussion with Donald Johnson, Clemson University.

[17] Donald Johnson, Clemson University, personal communication.

[18] Raymond Frisbie, Texas A&M University, personal communication

[19] Donald Johnson, Clemson University.

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On balance, we expect total insecticide use on grains, soybeans and cotton to decline, primarily but not exclusively because of declining use on cotton. A study by Headley (1978) supports this conclusion with respect to grains and soybeans. (The study was not concerned with cotton.) As part of the study Headley surveyed U.S. agricultural extension and research workers familiar with pest management practices in grains and soybeans. The 39 responses indicated a consensus that chemical insecticides would continue to play a major role into the 1990s, but that the trend of use would be declining. Resistant varieties, already of major importance for control of grain and soybean insects, would be on a rising trend. All other biological controls, e.g., deliberate use of parasites and predators, bacteria, viruses and phermones would remain of minor importance.

Herbicides

Importance of Conservation Tillage--

Table 5-5 shows a substantial increase from 1971 to 1976 in the amounts of herbicides applied to crops. Much of this increase must have resulted from the spread of conservation tillage. Conservation tillage means any of a variety of tillage practices which may differ in many details but which are distinguished from conventional tillage by three common features: (1) they rely on some instrument other than the moldboard plow to prepare the land for planting; (2) they leave enough residue from the previous crop on the soil surface to significantly reduce erosion; (3) they rely more on herbicides and less on mechanical cultivation to control weeds.

It is the third characteristic which is relevant for the present discussion.[20] Conservation tillage relies heavily on herbicides to control weeds. In no-till systems, a polar case of conservation tillage, the reliance typically is complete, i.e. weed control relies exclusively on herbicides. Other forms of conservation tillage may include some cultivation, but all usually require more herbicides per acre for weed control than conventional tillage. The amount more, however, is highly variable, judging from the literature (e.g., University of Illinois, pp. 6-7; Taylor, Reneau, and Trimble; Doster and Phillips; Walker; Amemiya; R.E. Phillips, et. al.).

There are a number of reasons why any form of conservation tillage may require more herbicides than conventional tillage, and why no-till definitely does. One might be called the substitution effect. Under specific conditions a given level of weed control may be achieved either by tillage or by herbicides, or by some combination of them. If control by tillage is reduced than a compensatory increase in the amount of herbicides applied is necessary to maintain the same level of control.

A second reason why conservation tillage likely will require more herbicides is the efficiency effect. Apart from the substitution effect,

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[20] The following discussion of conservation tillage is from Crosson, 1981.

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more herbicide must be applied to achieve a given level of weed control because some of the herbicide gets tied up by the crop residue which is a necessary concomitant of conservation tillage. Thus the efficiency of herbicide use is reduced (Siemens and Oschwald, citing Erbach and Lovely; Fenster and McCalla; Griffith, Mannering and Moldenhauer; University of Illinois; Robert Pope and Joseph Downs, University of Illinois, in discussion with one of the authors).

The environmental effect is a third reason why conservation tillage may require more herbicides than conventional tillage. The surface residue which accompanies conservation tillage usually reduces evaporation of water, so that typically soils are more moist with conservation tillage than with conventional tillage. The increased moisture improves the conditions for germination and growth of weeds (Griffith, Mannering and Moldenhauer; Pope and Downs in conversation with one of the authors).

The substitution, efficiency, and environmental effects are independent of one another, so their contributions to increased herbicide requirements with conservation tillage are additive. The literature does not indicate that all three effects are present in all cases of conservation tillage, and in fact there may be some circumstances, e.g., where weed problems are not serious in any case, where none of the three effects is important. In the usual case, however, it appears that one or more of the effects comes into play to increase herbicide requirements for conservation tillage relative to conventional tillage.

A recurrent theme in the literature is that over time perennial weeds become more important with conservation tillage. The reason is that herbicides do not attack the root systems of these weeds as tillage does, thus giving them a competitive advantage relative to annual weeds. It is not clear that the relative shift from annual to perennial weeds requires heavier applications of herbicides. It may mean instead that conservation tillage becomes uneconomic relative to conventional tillage in places where perennial weeds are a problem because some of these weeds cannot be adequately controlled with any amount of herbicides. Johnsongrass and bermudagrass in particular are in this category (Unger, Wiese and Allen; McWhorter and Jordan; Reicosky et. al.; Harrold, Triplett and Edwards; Pope and Downs in conversation with one of the authors). In such instances the economic disadvantage of conservation tillage results from unfavorable yields, not from the need for heavier applications of herbicides.

Judgments about future trends in the amount of herbicides applied to crops depend crucially upon prospects for the spread of conservation tillage. These prospects will be shaped by the comparative economics of conservation tillage and conventional tillage, and by public policies to deal with their respective environmental consequences.

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Economics of Conservation Tillage--

Table 5-11 gives estimates of land in conservation tillage in 1965 and subsequently, and Table 5-12 shows the regional distribution in 1978 and 1979. In the period covered by Table 5-11 there were no special public programs to promote adoption of conservation tillage. Its rapid spread since the mid-1960s, therefore, suggests that conservation tillage has important economic advantages over conventional tillage under a wide range of soil and climate conditions.

Costs per acre--A survey of the literature on tillage technologies (Crosson, 1981) indicates that total costs per acre are roughly 5 to 10 percent less for conservation tillage than for conventional tillage, the biggest differences being for sorghum and wheat and the smallest for corn and cotton. The difference for soybeans is intermediate. These differences reflect the net outcomes of lower costs for pre-harvest labor, for machinery, for fuel, and higher costs for pesticides, mostly herbicides. The lower labor and fuel costs result from the elimination of some (all in the case of no-till) cultivation to control weeds. Machinery costs typically are lower with conservation tillage because the practice involves less disturbance of the soil, hence does not require as powerful, and expensive, a tractor. We have not seen it stated in the literature but it seems likely that tractor maintenance costs also would be lower since with conservation tillage the farmer makes fewer passes over the field, which should reduce tractor wear and tear. The literature is unclear as to whether conservation tillage requires more or the same amount of fertilizer per acre to achieve given yields. We assume the same amount is required.

There is a clear consensus in the literature that conservation tillage requires "more" management than conventional tillage, but it is not so clear what this means for the costs of production of the two systems. Whether "more" management increases costs depends on what it costs farmers to acquire the additional management skills. These costs would be of three sorts: (1) out-of-pocket expenses, e.g. for subscriptions to farm management publications or tuition for a short course in conservation tillage practices; (2) time spent in reading the publications, attending the course, and talking with neighbors, extension agents, soil conservation technicians and vendors of conservation tillage technology; (3) the difference between the net income the farmer would earn if he stayed with conventional tillage and what he would earn from conservation tillage, i.e. the costs of learning-by-doing. The first kind of cost surely would be trivial, and the income foregone by engaging in the activities listed under (2) likely would be small also. The psychic costs of these activities could be high, however, if the farmer places a high value on his leisure. The pecuniary costs of learning-by-doing (the third kind of cost) clearly could be significant, depending upon the specific circumstances the farmer faces and how quick he is in acquiring the necessary knowledge through processes (1) and (2).

In estimating the future spread of conservation tillage increased management costs obviously must be considered, but in our judgment they are not likely to be of major importance. The history of American agriculture,

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TABLE 5-11. LAND IN CONSERVATION TILLAGE IN THE UNITED STATES (MILLIONS ACRES)

	USDA	% of Harvested Cropland	No-Till Farmer			% of Harvested Cropland
			No-Till†	Minimum Till	Total	
1965	6.6	2.3	NA	NA	NA	NA
1973	29.5	9.3	4.9	39.1	44.0	13.9
1975	35.8	10.8	6.5	49.7	56.2	17.0
1976	39.2	11.8	7.5	52.1	59.6	18.0
1977	47.5	14.1	7.3	62.7	70.0	20.7
1978	51.7	15.6	7.1	67.7	74.8	22.6
1979*	55.0	16.1	7.6	71.6	79.2	23.2

Sources: USDA, from Gerald Darby, Conservation Agronomist with the Soil Conservation Service. Based on reports from SCS county field offices.

No-Till Farmer, March 1979, pp. 4-5. Estimates by state agronomists of the Soil Conservation Service.

Harvested Cropland 1965-1979 from USDA, Feb. 1981.

*Preliminary

†Defined as "where only the intermediate seed zone is prepared. Up to 25% of surface area could be worked. Could be no-till, till-plant, chisel plant rotary strip tillage, etc. Includes many forms of conservation tillage and mulch tillage."

NA = not available.

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TABLE 5-12. CONSERVATION TILLAGE BY REGION

	1978		1979	
	Millions Acres	% of Cropland harvested	Millions Acres	% of Cropland harvested
Northeast	2.23	17.2	2.40	18.2
Lake states	6.78	18.2	6.93	17.9
Corn Belt	20.33	24.6	21.73	28.7
Northern Plains	23.65	32.2	25.01	33.3
Appalachia	5.42	29.8	5.83	30.7
Southeast	4.55	31.4	5.09	33.5
Delta	1.26	6.7	1.36	7.0
Southern Plains	2.24	7.5	1.98	6.1
Mountain	6.31	24.6	6.43	24.8
Pacific	1.90	10.9	2.35	13.5
Total	74.67	22.6	79.11	23.1

Sources: Land in conservation tillage from No-Till Farmer, March 1979.

Cropland harvested: USDA, Feb. 1981.

The No-Till Farmer estimates that in both 1978 and 1979 the sum of land in no-tillage, minimum-tillage and conventional tillage in the country as a whole was 300 million acres. The USDA (Feb. 1981) shows 331 million acres of cropland harvested in 1978 and 342 million acres in 1979. If some of the "missing" cropland were in conservation tillage, the figures in the table would be too low.

especially since the end of World War II, demonstrates that American farmers can quickly learn to use new, complex technologies when it is in their economic interest to do so. The extraordinary increases in this period in the use of fertilizers, pesticides, larger and more complex machinery, new seed varieties, new practices with respect to row spacing, and so on all attest to this, as well as to the efficiency of the U.S. agricultural establishment in developing new technologies and spreading the knowledge of how to use them. Indeed, the rapid spread of conservation tillage since the mid-1960s is itself testimony to the managerial capacity of farmers and the institutional structure which serves them. Accordingly, we do not believe that the costs of acquiring the managerial skills required by conservation tillage will significantly impede its spread over the longest term. Should conservation tillage not continue to expand, it likely will be for reasons other than increased costs of management.

Yields--If there were no difference in yields between conservation tillage and conventional tillage the cost advantage of conservation tillage

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would indicate its continued rapid substitution for conventional tillage. Comparative yields of the two systems thus must be considered.

It is important to distinguish between the short term (one or two years) and long term (decades) yield effects of tillage technologies. Conservation tillage reduces erosion by 50 to 90 percent compared to conventional tillage (more on this in the next section), and over the long term this can give conservation tillage a decisive yield advantage. Whether this occurs depends upon (1) the differential advantage of conservation tillage in reducing erosion; (2) the amount of topsoil and the nature of the underlying parent material; (3) the relation of changes in the amount of topsoil to changes in yield over time.

Depending upon these three conditions, the effect of the erosion factor in the choice of tillage technologies is either neutral or it favors conservation tillage. It can never favor conventional tillage. Consequently, where conservation tillage confers a short-term yield advantage farmers can be expected to choose that technology, given its cost advantage. Even where short-term yields of conservation tillage are less, however, farmers may yet choose that technology over conventional tillage if the erosion advantage of conservation tillage is sufficiently strong. The strength of the advantage depends upon (1) the annual differences in yields between conservation and conventional tillage as determined by the three factors listed above; (2) the cost to the farmer of substituting fertilizers or other inputs for the lost soil, thus offsetting the erosion induced decline in yields; (3) the length of time over which the yield differences matter to the farmer; (4) the farmer's expectations about future crop prices relative to current crop prices; (5) the rate of discount the farmer applies to future earnings. There is much speculation about these factors in the literature, but not enough hard facts to warrant firm generalizations about effects on farmers' choices between conservation tillage and conventional tillage.

The only confident statement we can make is one already made above: since conservation tillage never produces more erosion than conventional tillage and typically produces much less, the erosion effect on yields can never be to the disadvantage of conservation tillage. At worst it will be neutral, and it must often be positive, although without much additional research we cannot identify the specific situations in which this would be true or estimate the strength of the advantage.

The question of the long-term yield effects of erosion would be moot if conservation tillage had a clear short-term yield advantage over conventional tillage. The vast majority of the literature in fact deals with short-term yield differences and shows no clear pattern of advantage for either technology. Some studies show yields higher for conservation tillage, others show them lower and still others show no significant differences. The specific circumstances of soil, weather, and kind and quantity of weeds are of crucial importance in determining relative yield response, and these conditions differ widely, both spatially and even temporally in the same location. Other factors less often mentioned, and apparently less important are seed placement and soil compaction.

The key factors appear to be soil moisture and temperature, length of growing season and weeds. There is a strong consensus in the literature that in the plant root zone soil moisture generally is higher with conservation tillage and that in the spring soil temperatures are lower. Both of these conditions have a bearing on yields of conservation tillage relative to conventional tillage. In areas where rainfall is the principal factor limiting plant growth, as in part of the Northern Plains, the moisture conserving feature of conservation tillage is a distinct plus. Indeed, this appears to be the principal reason for the relatively widespread use of conservation tillage in that area (see Table 5-12). The moisture retaining characteristic of conservation tillage, however, is an advantage in any area subject to periods of drought or where soils are droughty. The characteristic is a distinct disadvantage, however, on poorly drained soils.

Cosper (1979) implicitly assuming that yield response is crucial in determining the competitiveness of conservation tillage relative to conventional tillage, finds the key to yield response in soil characteristics, with moisture retention capacity most important. More specifically, he asserts that "those physical features most significant in designating an acceptable tillage system include inherent drainage and soil wetness levels, structural stability, water percolation and surface soil texture. *Among these properties, soil wetness is perhaps the most restrictive in limiting the range of usable tillage systems*" (p. 17, emphasis added). Cosper uses these soil characteristics, especially wetness, to develop estimates of the maximum amount of land that could be economically put in conservation tillage in Ohio, Indiana, Illinois, and Iowa. His judgment that soil drainage is a key element in yield differences between conservation tillage and conventional tillage is widely shared in the literature.

Apart from soil wetness soil temperature is important to seed germination and seedling emergence and affects nutrient uptake by plants. If soil temperatures are too low, the availability and uptake of nutrients, particularly P and N, will be inhibited, slowing seed germination, seedling emergence, and subsequent early growth (Willis and Amemiya). Soil temperature generally is lower with conservation tillage than with conventional tillage, especially in the spring, because the crop residue reflects some of the sun's heat. On poorly drained soils temperatures may also be lower with conservation tillage because of the greater moisture content of these soils and the high heat capacity of water.

The delay in seed germination, emergence and early growth resulting from low soil temperatures may cause the seedlings to be relatively undeveloped and vulnerable when populations of disease organisms and insects begin to expand. The delay in early growth also is a disadvantage where crops require a full season for best yield performance, as is true of corn and soybeans in Illinois. Indeed, R.E. Phillips *et. al.* assert that the delay in spring planting required by lower soil temperatures is a disadvantage to conservation tillage throughout the central and northern United States. Amemiya (p. 33) also asserts that the low soil temperature associated with conservation tillage is a "serious obstacle to adoption" of the technology in the northern Cornbelt.

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The length of the growing season has a differential effect on yields of conservation tillage and conventional tillage in two ways. One has just been indicated. As the growing season shortens, the delay in planting imposed by the cooler soil temperatures of conservation tillage imposes an increasing yield penalty on that practice. Hence the attractiveness of conservation tillage diminishes as one moves from south to north. However, as one moves from north to south the growing season lengthens, and conservation tillage opens up opportunities for double-cropping not available with conventional tillage. This is the other effect of the growing season on yields. Because conservation tillage permits the planting of a crop directly in the stubble of a preceding crop immediately after harvest it saves time. The time saved may be enough to take a second crop with conservation tillage where this would be impossible with conventional tillage. Double-cropping, of course, increases yields, thus reducing average costs of land and other fixed inputs. Double-cropping with conservation tillage already is practiced in the southern Cornbelt and Southeast, typically with wheat followed by soybeans.

Inadequate weed control is a major factor adversely affecting yields with conservation tillage. Weeds compete with crops for sunlight, moisture and nutrients, and where they cannot be controlled yields will suffer. In some areas and for some weeds, adequate control with herbicides is difficult or impossible. It was noted earlier that perennial weeds typically become more important with uninterrupted use of conservation tillage (Reichert; Davidson and Santelmann; Griffith, Mannering, and Moldenhauer; Randell and Swan; Amemiya; Wiese and Staniforth). A companion theme is that there are no fully effective herbicides for controlling certain perennial weeds and that conservation tillage will face severe difficulties or should not be used at all in areas infested with these weeds. Johnsongrass, nutsedge, broomsedge, bermudagrass, bullnettle and bindweed are commonly mentioned.

Summary on Economics--

In production of corn, sorghum, wheat, soybeans, and cotton conservation tillage has a cost advantage of roughly 5 to 10 percent relative to conventional tillage. It follows that in areas with well drained soils, adequate control of weeds with herbicides, and potential for double-cropping economics would clearly favor conservation tillage. Two questions arise: (1) is the present geographical distribution of conservation tillage consistent with this assertion? (2) Does the assertion provide any insights to the role of economics in the future spread of conservation tillage?

There is little information with which to address either of these questions. With respect to the first, however, Table 5-13 is relevant. Column (1) in the table is based on Cosper's analysis of soil types in the four states, with special attention to soil drainage characteristics. The column indicates that as one moves from the eastern to the western Cornbelt the percentage of tillable land with drainage characteristics favorable to conservation tillage increases. Column (2) indicates a similar progression in the percentage of land actually in conservation tillage. The two columns, therefore, are consistent with the hypothesis that soil drainage is a key

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TABLE 5-13. PERCENTAGES OF LAND APT FOR CONSERVATION TILLAGE AND IN CONSERVATION TILLAGE, OHIO, INDIANA, ILLINOIS, AND IOWA

	(1) Percent Apt for conservation tillage*	(2) Percent in conservation tillage, 1979†
Ohio	47.5	8.0
Indiana	53.4	22.8
Illinois	65.9	28.0
Iowa	76.4	38.9

*From Harold Cosper (p. 26). Land is "tillable acres", and for each state is almost exactly the same as the sum of cropland and pasture as reported in the USDA's National Resources Inventory of 1977.

†From No-Till Farmer, March 1979.

factor in determining the yields and hence the economic feasibility of conservation tillage.

Cosper is extending his analysis of soil types to the Northern Plains, but those estimates are not available as of this writing. Nor are there similar estimates for any other region of the country. Consequently, we are unable to judge whether the distribution of conservation tillage outside the Cornbelt is consistent with the hypothesis that soil drainage is a key factor.

There are other useful hypotheses, however, which can be examined. Because of the semiarid climate in the Northern Plains (North Dakota, South Dakota, Nebraska, and Kansas) one would expect the percentage of land in conservation tillage in the region to be relatively high. However, because conservation tillage lowers soil temperature in the spring, thus delaying planting relative to conventional tillage, the percentage of land in conservation tillage would be expected to decline as one moves with the diminishing growing season from Kansas to North Dakota. For the same reason one would expect the percentage of conservation-tilled land in the Lake States (Michigan, Wisconsin, and Minnesota) to be less than in the Cornbelt. Because of the favorable prospects for double-cropping with conservation tillage in the Southeast (Lewis) the percentage of conservation tilled land ought to be relatively high in that region, while it ought to be relatively low in the Mississippi Delta and the Southern Plains (Texas and Oklahoma) because of the relatively large amounts of land in cotton in those regions and the problems of controlling weeds, particularly perennial weeds, with herbicides in cotton.

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TABLE 5-14. PERCENT DISTRIBUTION OF CROPLAND IN CONSERVATION TILLAGE, VARIOUS STATES AND REGIONS, 1979

	Percent
Kansas	50.1
Nebraska	47.1
South Dakota	34.3
North Dakota	13.2
Northern Plains	32.7
Corn Belt	27.7
Lake States	23.4
Southeast	50.7
Delta	7.8
Southern Plains	6.5

Source: No-Till Farmer, March 1979. The percentages are higher than those in Table 5-12 because we used the No-Till Farmer estimates of total cropland to calculate the percentages. These estimates are lower than those of the USDA, used to calculate the percentages in Table 5-12.

Table 5-14 shows that the regional distribution of conservation tillage in 1979 was generally consistent with these expectations.

It appears that the available data support a positive answer to the first question posed above: the present regional distribution of conservation tillage is consistent with what the literature tells us about the factors affecting yields of conservation tillage relative to yields of conventional tillage. Given that, what can we say in answer to the second questions--the role of economics in the future spread of conservation tillage?

With respect to costs, the competitive position of conservation tillage relative to conventional tillage probably will be strengthened somewhat if energy prices rise over the long-term, as is now generally expected. However the overall impact probably will not be large. Differences in fuel costs are a small part of the total cost differences between the two technologies. Moreover, an increase in fuel costs is likely to trigger an increase also in pesticide costs since most pesticides are petroleum based. This would weaken the competitive position of conservation tillage. In the discussion of costs we assumed no difference between the two technologies with respect to fertilizer requirements, but if in fact conservation tillage requires more fertilizer, particularly nitrogen, to achieve comparable yields, as much of the literature suggests, rising energy prices would weaken the competitive position of conservation tillage on this score also.

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On balance, we do not expect changes in resource requirements and costs to significantly alter the present competitive position of conservation tillage relative to conventional tillage over the long-term. The small present advantage of conservation tillage is expected to remain, neither widening nor shrinking by much. So far as the future spread of the technology depends upon economics, therefore, factors affecting comparative yields are likely to be most important.

If the demand for U.S. crop production and trends in crop technology behave as we have projected, it is likely that the erosion advantage of conservation tillage will favor the technology more strongly in the future than it probably has so far. The reason is that much of the additional land that would be needed for crop production in 2010 would be more erosive than land now in production.[21] The negative effects of erosion on the yields of such land likely would be more pronounced than on present cropland and therefore of more immediate concern to the farmer. The use of conservation tillage on these marginal lands should appear attractive.

Comparison of the amount of land now in conservation tillage in the Cornbelt with the amount with potential for the technology, judging from soil characteristics, indicates substantial room for expansion (see Table 5-13). How much of the potential might be realized is impossible to say, but the table raises some questions in this regard. The small amount of land in conservation tillage in Ohio (8.0 percent when the potential is 47.5 percent) suggests either that one or both of the numbers is wrong or that something other than soil characteristics is limiting the spread of conservation tillage in Ohio. Judging from entries in the literature as much research on conservation tillage has been done in Ohio as in any other state and more than in most.[22] It is hard to believe that the failure of conservation tillage to be more widely adopted in Ohio is because farmers do not know enough about its advantages. A more plausible alternative explanation (if we accept the numbers) is that for some reason weed control with herbicides is especially difficult in Ohio. That problems of weed control may be the principal obstacle to further spread of conservation tillage, not only in Ohio but elsewhere in the Cornbelt, is a view held by a number of knowledgeable observers.[23]

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[21] Much of any land converted to crops would come from class I-IV land now in pasture. The USDA's Natural Resources Inventory of 1977 shows that 63 percent of present pasture land in classes I-IV has an erosion hazard. The comparable figure for present cropland is 50 percent.

[22] G.B. Triplett and his colleagues at the Ohio Agricultural Research and Development Center at Wooster have been researching conservation tillage for years and have published their results widely.

[23] Griffith, Mannering and Moldenhauer. Also Robert Pope and Joseph Downs, University of Illinois, personal communication.

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We already have suggested that the problem of controlling weeds, particularly perennials, with herbicides is the main reason for the small amounts of land in conservation tillage in the Mississippi Delta and the Southern Plains. If weed control is also the principal limiting factor in the Cornbelt then it would be fair to say that for the country as a whole the future expansion of conservation tillage depends more on improved techniques for controlling weeds, particularly perennials, than on any other single development. What is needed are new chemicals that would be effective against these weeds as well as new techniques of herbicide applications. Much research and development now is underway to meet both of these needs. For example, promising results have been obtained in Ohio with post-emergence herbicides for controlling both perennial and annual grasses soybeans. It is believed that these materials will also prove effective in dealing with perennials in a corn-soybean rotation. Techniques for using ropewick devices for post-emergence applications of contact herbicides also are being developed.

We expect these research and development efforts to receive additional impetus because of the value of conservation tillage in containing the erosion threat posed by the expansion of agricultural production onto marginal lands. Consequently, we anticipate that the present limits imposed by weed problems to the spread of conservation tillage will be pushed back. We have no solid base for judging how far this may go, but we believe that economic factors could induce farmers to adopt conservation tillage on 50 to 60 percent of the nation's cropland by 2010. (In 1979 16 to 23 percent of cropland was in conservation tillage, depending upon the data sources--see Table 5-11.)

Future Trends in Herbicide Use--

Table 5-15 indicates how much herbicide would be used on main crops in 1985 and 2010, given our projections of crop acreage, if the percentages of acres receiving herbicides and the amounts applied per acre are the same as in 1976. If conservation tillage spreads as we expect and substitutes for herbicides in conservation tillage systems are not developed, per acre applications of herbicides for corn, soybeans and wheat will rise from 1976 levels. The continued spread of conservation tillage based on currently available herbicides, therefore, implies larger applications of herbicides in 1985 and 2010 than shown in Table 5-15. We have no basis for estimating the additional amount, but it could be substantial, particularly if the percentage of wheat land receiving herbicides is increased. (Most corn, soybean and cotton land already is treated with herbicides--see Table 5-6.) The environmental implications of the trends in herbicide use, in use of insecticides, and of our projections of crop production and land use are discussed in the following section.

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TABLE 5-15. HERBICIDES APPLIED TO CROPS (MILLIONS LBS. ACTIVE INGREDIENTS)

	1976	1985	Percent increase from 1976	2010	Percent increase from 1976
Corn	207.1	233.0	12.5	269.3	30.0
Cotton	18.3	23.8	30.1	25.5	39.3
Wheat	21.9	23.1	5.5	28.0	27.9
Soybeans	81.1	115.9	42.9	179.1	121.0
Total of above	328.4	395.8	20.5	501.9	52.8
Total of all crops	394.3				

Sources: 1976 from Eichers, Andrilenas and Anderson. 1985 and 2010 assume that the percentages of each crop receiving herbicides and the amounts applied per acre are the same as in 1976, and total acreage in each crop is as we have projected. See text discussion for qualification of these assumptions.

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SECTION 6

ENVIRONMENTAL IMPACTS OF PROJECTED PRODUCTION AND RESOURCE USE

INTRODUCTION

The environmental impacts considered are those resulting from increased use of fertilizers and pesticides, from the expansion of irrigation, and from erosion. Comprehensive and generally acceptable quantitative estimates of these impacts are not available, and perhaps not possible, even theoretically. One reason is lack of basic knowledge, e.g., the contribution of phosphorus fertilizer to eutrophication of water bodies compared to that of municipal wastes; or the fate of pesticides after they are applied to farmers' fields. A second major reason is the conceptual difficulty of valuing some of these impacts, e.g., human illnesses or deaths from pesticides.

For these reasons our assessment of environmental impacts makes no attempt at quantification in the sense of attempting to assign monetary values to the impacts. Instead we seek to make judgments on two questions: (1) are the impacts presently of such a nature as to require new policies or modification of existing policies to deal adequately with them, (2) given our projected increases in resource use, are the future impacts likely to be more or less severe than at present? These judgments set the stage for the discussion in the following section of policy issues and options.

FERTILIZER

Nature of the Environmental Impacts

The principal concerns about fertilizers in the environment have to do with effects of nitrogen in water on human and animal health and of nitrogen and phosphorus in accelerating eutrophication of water bodies by stimulating growth of aquatic plants.[1]

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[1] Denitrification of nitrate-N releases nitrogen oxides, one of which, nitrous oxide (N_2O), may attack the earth's ozone shield. The resulting increase in solar radiation reaching the earth's surface would increase the risk of skin cancer. This possibility received considerable popular attention in the mid-1970s, particularly after press reports of work done by Michael McElroy at Harvard. According to Aldrich (1980, pp. 222-223) a sub-

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Nitrates in water may constitute a hazard to both humans and animals that drink the water, not because the nitrates themselves are particularly toxic but because of their potential for conversion to nitrites which are toxic, or can be in sufficient concentration. Babies are more likely to suffer from nitrite poisoning than adults. Deaths and illnesses among farm animals also have been attributed to nitrite intoxication (Luhrs). Nitrogen gas dissolved in water or nitrogen in ammonia may kill or injure fish (Patrick).

Eutrophication is a process involving the nutrient enrichment of lakes and reservoirs, the resultant growth of plant life, and the subsequent decline in the water's dissolved oxygen supply because of the oxygen demand of decaying plants. If severe, eutrophication makes the water incapable of supporting fish and spoils its value for some kinds of recreation. Eutrophication is a natural process, but it can be accelerated by the addition of nutrients supplied by man, including nitrogen and phosphorous carried by run-off water and soil eroded from farmland.[2] The amounts of these nutrients may be very small yet have significant effects in stimulating growth of aquatic plants. According to Holt, Johnson, and McDowell as little as 10 parts per billion (ppb) of phosphorus and 100 ppb of nitrogen are enough to support growth of undesirable amounts of aquatic plants.

Present Severity of the Problems

Some years ago one of the authors assessed the severity of the nitrate problem in the United States and agriculture's contribution to it in the following words (Crosson and Frederick, pp. 192-195):

> The evidence about the present seriousness of the environmental hazards of fertilizers is not easy to interpret. Numerous studies show the presence of nitrates in groundwater, for example, in parts of Connecticut, Long Island, Illinois, the High Plains, Minnesota, and California. (Martin, Fenster and Hanson; Miller, DeLuca, and Tessier). In some of these places the nitrate-N level has exceeded ten parts per million, the standard for drinking water set by the Public Health Service. It is not clear, however, that fertilizer used in agriculture is the principal source of tne nitrate in these waters. Martin and coauthors cite a study by Smith of 6,000 rural water supplies in Missouri which concluded that animal wastes and

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(footnote continued from page 6-1)

sequent study by the National Academy of Sciences indicated a lag of about 100 years between the application of nitrogen fertilizer and effect upon the ozone shield. Moreover, even a very large increase worldwide in nitrogen fertilizer use would reduce the ozone shield only 1.5 to 3.5 percent by 2100. Perhaps for these reasons the issue has faded from public discussion. We do not consider it further in this report.

[2] Municipal and industrial wastes also are major sources of nutrients which contribute importantly to eutrophication.

septic tank drainage were the principal sources of nitrates. Studies in Minnesota show that rural wells were contaminated by nitrate long before fertilizer use became important, and that between 1899 and 1963 change in the quality of water in major aquifers was minor. A study of an area near San Luis Obispo, California, showed that nitrate in groundwater "...was substantial and mostly associated with the native soil organic matter complex supplemented with sewage waste from area homes and to a lesser extent from lawn and farm fertilization." (Miller, DeLuca and Tessier, P. 309) In their study of groundwater pollution in the northeastern states Miller and coauthors assigned a "moderate" priority to fertilizer for additional research and control measures while giving high priority to domestic, municipal, and most other sources of wastes.

De Luca

The extent of fertilizer pollution of surface waters in the United States also is unclear, although the problem seems to have been less investigated. In a study of the southern High Plains Goldberg concluded that "nitrogen fertilizer applied to the farmland adds little nitrate to the surface water." (Goldberg) Aldrich says that the nitrate content of rivers in the central Corn Belt for which long-term records are available shows an upward trend. The nitrate content of the Mississippi River at the point where it leaves the Corn Belt about doubled from the mid-1950s to the mid-1970s but was still less than the maximum acceptable amount set by the U.S. Public Health Service for drinking water. The nitrate content of the Illinois River increased about one-quarter in this period but still was only about one-half of the Public Health Service's standard, while the nitrate in the Missouri declined about 50 percent between 1950 and 1970. In some small creeks and rivers in Illinois, however, the nitrate content sometimes exceeds the standard. (Aldrich, 1976)

The National Academy of Sciences cites a report on fertilizer pollution in Illinois by the Illinois Pollution Control Board (IPCB) which concluded that "there is no factual basis for imposing restrictions on the use of fertilizer at this time." The conclusion applied both to nitrogen and phosphate fertilizers....The EPA subsequently issued a policy statement in general agreement with the decision of the IPCB regarding fertilizer, but it also stressed the need for additional information. (National Academy of Sciences, 1975b, pp. 92-93)

In our reading of the evidence on the environmental threats of fertilizer, two important aspect stand out. One is that human deaths or illnesses attributable to nitrite poisoning are extremely rare. Animal poisonings are more common, but where caused by drinking water the nitrate content of the water was seven to fifteen times the standard set by the U.S. Public Health Service. (Aldrich, 1976) Enforcement of the standard should eliminate such instances. Fish kills or injuries attributable to forms of nitrogen in surface water also are of small overall importance.

> The second aspect is that much of the nitrogen and phosphorus found in water bodies comes from municipal and industrial discharges and from the natural leaching of these nutrients already in the soil.
>
> Consideration of these two aspects of the evidence leads us to conclude that with present levels of use fertilizers do not pose threats to the environment so severe that changes in present policies are required to deal with them.

We believe this assessment of the nitrate problem is still valid. After a thorough review of the data on nitrates in surface waters, Aldrich (1980) concludes:

> The evidence is convincing that, based upon available data, the nitrate issue in surface waters in the United States in relation to health is limited mainly to the midwest and to certain rivers in intensively farmed regions of California. (p. 141)

Aldrich's review shows that even in the midwest nitrate concentrations in rivers only occasionally exceed the 10 ppm nitrate-N concentration standard set by the U.S. Public Health Service.

Nor have we found anything in the more recent literature to alter our judgment about the contribution of nitrogen fertilizers to contamination of groundwater. The Council on Environmental Quality (CEQ, 1979) has asserted that surface and subsurface disposal of wastes are among the major sources of groundwater contamination in the country. Disposal of industrial wastes in this manner is mentioned in particular. In this context the CEQ (1979, pp. 110-111) notes that infiltration of nitrates from nitrogen fertilizers is another important source of groundwater contamination. However, earlier in the same report (pp. 107-109) the CEQ presents a table summarizing groundwater quality conditions in eighteen river basins making up the forty-eight contiguous states which mentions fertilizer contamination in only two regions, the Souris-Red-Rainey (northern Minnesota and North Dakota) and the Pacific Northwest. Irrigation return flow is mentioned as a contaminant of groundwater in the Great Basin, and this presumably includes nitrates from fertilizer, although the CEQ report does not say so explicitly. The table conveys the strong impression, however, that with the exception of local "hotspots" in the regions mentioned, contamination of groundwater by nitrogen fertilizer is not presently a major problem.

This interpretation is supported by a more recent publication by the CEQ (Jan. 1981) dealing with contamination of groundwater. An EPA report (1977b) is cited as identifying the disposal of industrial wastes at industrial impoundments and solid waste disposal sites as the most important source of groundwater contamination. Septic tanks, municipal waste water, mining and petroleum exploration and production are listed as of secondary importance. Agriculture is not mentioned as of even secondary importance as a source of groundwater pollution.

A study of the Santa Maria valley in California in 1976 showed that 39 percent of the nitrogen fertilizer applied to 57,000 acres of vegetable,

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field and fruit crops was leached below the root zone, but there is no indication that nitrate concentration in groundwater in the area exceeded 10 ppm as a consequence (Lund et al.). A study of the Upper Santa Ana River basin of California in the early 1970s revealed several "hotspots" where nitrate concentrations were high (Ayers). In the dairy farm area of the Chino Basin, a small part of the whole basin, nitrate-N concentrations at the top of the water table underlying cropland sites averaged 45 ppm. Deep well water in the same vicinity averaged 6 ppm. Ayers infers from these numbers that the dairy wastes had not yet had full impact on nitrate-N concentrations in the groundwater. He evidently believes that animals rather than fertilizers are the main contributors to the build-up of nitrate-N in the groundwater.

A problem area that has emerged since our previous review of the literature on fertilizer pollution (or which our review missed) is the Sandhills region of Nebraska. In irrigated parts of that region nitrate-N concentrations in groundwater have risen to 20 ppm. With good irrigation management concentrations should not rise above 20 to 25 ppm, but with continued expansion of irrigation in the area they are not likely to fall below those levels.[3]

Eutrophication--

The Environmental Protection Agency conducted a nationwide eutrophication survey between 1972 and 1977 which found that two-thirds of the 800 lakes surveyed were eutrophic and another 4 percent were hypereutrophic.[4] On its face this would seem to suggest that eutrophication is a major national problem. It is not so treated in the cited CEQ report, however, nor in recent annual reports to Congress by the EPA on the condition of national water quality. This is not to say that the CEQ and the EPA reports dismiss eutrophication as a national problem. They do not. But the reports convey no sense that the problem is of the magnitude suggested by the finding of the EPA's eutrophication study that over 70 percent of the lakes surveyed were eutrophic or hypereutrophic. The reason, perhaps, is that eutrophication is a matter of degree, and a lake classed as eutrophic under the EPA definition still can be fishable and swimmable and provide other recreational values.

Whatever the seriousness of the eutrophication problem, fertilizers apparently contribute less to it in most instances than other sources of nutrients. Phosphorous is usually the nutrient limiting plant growth in lakes and reservoirs, and municipal, industrial, and other non-agricultural

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[3] Darryl Watts, University of Nebraska, cited in Frederick.

[4] Council on Environmental Quality (1979, p. 92). According to the CEQ a eutrophic lake usually has murky, greenish water and measurable amounts of plant productivity, and a hypereutrophic lake has very murky water and extremely high levels of plant biomass.

The EPA survey over-represented lakes receiving discharges from municipal sewage treatment plants. Such lakes likely would be more eutrophic than lakes not receiving such discharges (CEQ, 1979, p. 92, footnote 16).

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wastes typically contribute more phosphorus (and other nutrients) to these water bodies than fertilizers applied in agriculture (CEQ, 1979, p. 95). In discussing eutrophication in Lakes Erie and Ontario, the most seriously affected of the five Great Lakes, the CEQ report puts high loads of nutrients from municipal sewage ahead of those from agricultural and urban runoff as the principal cause. According to the EPA (1977a, p. 9), control of phosphorous discharges from municipal waste treatment plants is expected to have a major effect in reducing eutrophication in heavily populated regions.

Future Severity of the Problems

Our projections in the previous section show increases in total nitrogen applied of 40 percent from 1977/79 to 1985 and of 87 percent from 1977/79 to 2010. For phosphorus, the increases are 30 percent and 68 percent respectively (see Table 5-3).[5]

The projected increases of fertilizers applied to the four main crops (corn, wheat, soybeans, and cotton) from 1977/79 to 2010 are 60 percent for nitrogen and 70 percent for phosphorus. Seventy to 75 percent of the increase in nitrogen applied to these crops and 80 percent of the increase in phosphorus is attributable to the increased acreage in corn, wheat, and soybeans.[6] The percentage increases for nitrogen are less for the four main crops than for total applications because "all other" uses of nitrogen are projected to increase faster than uses on the four main crops. "All other" uses of fertilizer includes that put on crops other than the main four, as well as that used on golf courses, parks, home gardens, and lawns, and so on.

In Section 4 we assumed that land in crops other than main crops would be the same in 1985 as in 1977, and that in 2010 land in these crops would be 16 million acres less than in 1977, reflecting a 10 million acre decline in land in hay and a 6 million acre decline in land in sorghum, oats, and barley. We have not projected fertilizer applications per acre of land in "other crops," but we do not expect much increase, for the same reasons that little increase is expected in per-acre applications to main crops. It follows that most of the projected increase in "all other" uses of fertilizer is for non-crop purposes. Since we are interested in this study in the environmental impacts of crop production, we give no further attention to "all other" uses of fertilizer. We note, however, that should concern about environmental impacts of fertilizers mount in the future the "all other" uses likely will require special attention.

The environmental impacts of the projected increases in fertilizers used on the four main crops depend on how much of the additional nutrients move to ground and surface water and on existing nutrient concentrations in the water. For the moment we focus on movement of the additional nutrients.

5p

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[5] There is little concern about the environmental impacts of potassium fertilizers, and we do not consider them here.

5-3

[6] We project a small decline in fertilizer applied to cotton by 2010, so we do not consider use on cotton in this discussion (see Table 5-3 in Section 5).

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Movement of Nutrients--

For several reasons we expect the increase in movement of nutrients to water bodies to be proportionally less than the increase in amounts of fertilizers applied. As noted above, 70 to 80 percent of the increase in amounts applied of both nitrogen and phosphorus from 1977/79 to 2010 is because of the expansion of land in corn, wheat, and soybeans. About 16 million acres of the additional land is now in hay (10 million acres), sorghum, oats, and barley (6 million acres). We have no completely reliable information on how much fertilizer currently is applied to these 16 million acres, but several sources suggest a conservative range of 50 to 75 pounds per acre of both nitrogen and phosphorus (International Minerals and Chemical Corporation). If we assume 60 pounds, then the 16 million acres currently receive 960 million pounds of nitrogen and phosphorus per year. Consequently the *net* increases by 2010 in the amounts of these materials applied to corn, wheat, and soybeans would be 960 million pounds less than the gross amounts we have projected. In percentage terms, the net projected increase for nitrogen would be 53 percent compared with a gross increase of 66 percent. For phosphorus the net increase would be 51 percent compared with a gross increase of 75 percent.

The increase in movement of nutrients may not be proportional to the net increases in amounts applied also because fertilizer technologies are likely to become more efficient in response to higher prices, as discussed in the previous section, and because of the expected increase in conservation tillage relative to conventional tillage.

Effects of Increased Efficiency--The anticipated adoption of fertilizer materials and practices which reduce nutrient losses would tend to hold the increase in movement of nutrients below the increases in total amounts applied. We have no solid basis, however, for estimating how much losses might be reduced. Stanford cites a study in Nebraska indicating that losses of sidedressed nitrogen were 30 percent less than losses of N applied in the fall or spring. Stanford goes on to assert that an "appreciable" increase in nitrogen efficiency can be achieved by more realistic recommendations of application rates and proper timing of application, but he gives no numbers.

Nitrogen fertilizer losses vary widely from place to place, depending upon soil moisture and temperature and other factors. According to Hinish, losses can range from 20 to 60 percent. For illustrative purposes we assume average nitrogen losses of 40 percent and that improvements in practices and materials reduce losses by 20 percent between 1977/79 and 2010. With these assumptions the projected 53 percent net increase in nitrogen applied to corn, wheat, and soybeans would result in a little more than 20 percent increase in nitrogen losses.[7]

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[7] For example:

	1977/79	2010
Amount of nitrogen applied	100	153
Percentage lost	40	32
Amount lost	40	49

The amount lost would increase a little more than 20 percent.

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Aldrich (1980, p. 119) expects use of nitrogen fertilizer in the Cornbelt to increase. He argues, however, that higher prices, among other factors, will induce farmers to use fertilizer more efficiently. Indeed, he asserts that the increase in amount of nitrogen applied "...will closely follow the rise in efficient utilization by crops."

Losses of phosphorous fertilizers range from 60 to 80 percent (Hinish). Assuming an average of 70 percent and that losses fall by 20 percent by 2010, the projected 51 percent net increase in phosphorus applied would result in about a 20 percent increase in losses.

fall

Effects of Tillage Technologies--Losses of fertilizers applied to land in the three main crops in 2010 also will be influenced by the kind of tillage technologies used on this land. We concluded in the previous section that the economics of conservation tillage would favor its spread to 50 to 60 percent of the nation's cropland by 2010 (increasing its share two to three times). Most conservation tillage is on corn, soybean, and wheat land, so we anticipate conservation tillage of land in these crops to increase significantly by 2010.

The effects of the spread of conservation tillage on movement of nutrients to water bodies is uncertain. It will be shown below that conservation tillage greatly reduces erosion compared to conventional tillage, and a number of studies have demonstrated that most of the nitrogen and phosphorus moved from farmers' fields to surface water bodies is carried by eroded soil.[8] The nitrogen so moved is in the organic form and when deposited with sediment in rivers, lakes, and reservoirs, is mineralized to the nitrate form only very slowly. Consequently the advantage of conservation tillage in reducing erosion, and hence losses of organic nitrogen, does not significantly reduce the impact of nitrogen on water quality.

Wauchope, McDowell, and Hagen cite a number of studies indicating that, unlike the nitrogen carried by eroded soil, 5 to 40 percent of the phosphorus so carried is available to support aquatic plant growth. However, the concentration of fertilizers in the top soil layer is higher with conservation tillage than with conventional tillage, so nutrient concentrations in sediment from conservation tillage fields also are higher. Consequently, while the reduction in erosion with conservation tillage tends to reduce losses of available phosphorus, the higher concentration in eroded soil tends to increase them. Studies by Barisas et al. and Johnson et al. showed, however, that in the usual case the reduction in losses of available P because of less erosion more than offset the increase in losses because of higher concentration in the eroded soil, so the net effect was smaller losses. ✓

According to Wauchope, McDowell, and Hagen there is considerable evidence that concentrations of nitrate nitrogen, ammonia, and available phosphorus are higher in runoff water from conservation-tilled fields than from conventionally-tilled fields. Barisas et al. found this also. Johnson

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[8] Barisas et al. and studies cited therein.

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et al. reported no significant differences among tillage practices with respect to concentrations of nitrate nitrogen and ammonia in runoff water, but concentrations of soluble P were higher with conservation tillage. Concentrations in runoff water are higher both because nutrient concentrations are higher in the top soil layer and because of leaching of nutrients from the crop residues found with conservation tillage.

The amount of runoff water typically is less with conservation tillage because the surface residue and rougher soil texture characteristic of the technology reduce the velocity of water flow, permitting more water to remain on the field. Because the concentration of nutrients in runoff typically is higher with conservation tillage, the reduction in runoff water does not necessarily reduce the concentration of nutrients in receiving waters. Total nutrients in runoff water conceivably could be greater with conservation tillage, in which case the technology clearly increases the nutrient content of the receiving waters compared to conventional tillage. Even if total nutrient loss in runoff water is less with conservation tillage, the effect on nutrient concentrations in receiving waters is uncertain. If, compared to conventional tillage, conservation tillage reduces the amount of nutrient delivered proportionally less than the amount of water delivered, conservation tillage will *increase* the nutrient content of the receiving waters. It will *decrease* the nutrient content of the receiving waters if it reduces the amount of nutrient delivered proportionally more than it reduces the amount of water delivered. Both these conditions are consistent with higher concentrations of nutrients in runoff water with conservation tillage.

The reduction in runoff water with conservation tillage may result in more infiltration of nitrate-N to graoundwater than with conventional tillage. Unlike nitrate-N phosphorus is strongly adsorbed by soil and so does not leach to groundwater in significant amounts.

The discussion suggests that conservation tillage may pose a greater threat to groundwater quality than conventional tillage because of increased leaching of nitrate-N, but that the comparative effects on delivery of nitrate-N to surface waters is too dependent on specific local conditions to warrant a general conclusion.

The effect of the spread of conservation tillage on the threat of phosphorus to water quality also is not clear. The outcome depends upon the reduction in available phosphorus carried by eroded soil relative to the increase carried by runoff water. In general, the advantage of conservation tillage with respect to the total amount of available phosphorus delivered to water bodies will be greater (1) the greater the reduction in erosion: (2) the smaller the difference between conservation and conventional tillage in concentration of total P in sediment; (3) the greater the ratio of available P to total P in sediment; (4) the higher the sediment delivery ratio; (5) the smaller the difference between the two tillage systems in concentration of phosphorus in runoff water. While erosion typically will be substantially less with conservation tillage and the concentration of available P in both sediment and runoff water higher, the rangeof difference in these and the other variables is large. Consequently, no general conclusion about

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the effect of the spread of conservation tillage on the delivery of phosphorus to water bodies seems warranted.

While we cannot say how the shift to conservation tillage would affect delivery of phosphorus and nitrate-N to surface waters, it seems reasonably well established that the shift would increase movement of nitrates to groundwater. Thus the shift probably would offset to some extent the effect of more efficient materials and practices in reducing nitrate losses. We lack data to precisely estimate the net outcome, but some plausible numbers suggest that the increase in nitrate losses could be about 30 percent. This would be the case if conservation tillage of land in corn, wheat and soybeans increased from 30 percent in 1977/79 to 60 percent in 2010, if nitrate losses were 50 percent from conservation-tilled land and 40 percent from conventionally-tilled land, and if losses with both kinds of tillage were 20 percent less in 2010 than in 1977/79.[9]

We conclude that from 1977/79 to 2010 losses of nitrogen fertilizer from land in corn, wheat, and soybeans will increase significantly less than the projected 66 percent gross increase in amounts applied. The increase in phosphorus losses also is likely to be significantly less than the gross projected increase of 75 percent, although this outcome is clouded by uncertainty about the effect of the shift to conservation tillage on phosphorus losses.

Whether these increases in nutrient losses would cause water quality problems depends upon nutrient concentrations in the receiving waters. Since existing concentrations of nitrate-nitrogen do not appear to pose serious problems except, perhaps, in a few local "hot spots" around the country, some increase in concentrations evidently could be accommodated without serious consequence. Whether an increase on the order of 30 percent would be cause for concern we are unable to say.

Our earlier discussion indicated that municipal wastes are a major source of phosphorus in water and that significant reductions in this source are expected as a result of increased investment in municipal waste treatment around the country. This suggests that the increased losses of phosphorus from land in corn, wheat, and soybeans would not cause major increased damage to water quality. Accordingly, we do not further consider phosphorus losses.

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[9] For example:

	1977/79			2010		
	Conservation tillage	Conventional tillage	Combined amount	Conservation tillage	Conventional tillage	Combined amount
Amount of nitrogen applied	30	70	100	91.8	61.2	153
Loss percentage	50	40	43	40	32	38.4
Amount lost	15	28	43	36.7	19.6	56.3

Total losses would increase about 30 percent.

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The estimates so far presented of fertilizer applications and losses are for the nation as a whole. They mask widely varying regional increases in application and losses reflecting primarily regional differences in projections of land in the three main crops. The smallest relative increases in nitrogen applied--all about 40 percent--are in the Lake States, Cornbelt, and Northern Plains. The largest nitrogen increases are in the Mountain States (280 percent), Southeast (195 percent), Southern Plains (180 percent), Pacific (150 percent), and Delta (100 percent).

We expect that in both the Cornbelt and Northern Plains about 2 million acres of land now in sorghum, oats, and barley will be converted to corn, wheat, and soybeans by 2010. Consequently, the net increases in nitrogen applied in these regions would be somewhat less than the projected 40 percent gross increase. Allowing for more efficient nitrogen materials and practices and for the spread of conservation tillage, nitrate losses in these regions, and in the Lake States, might increase 20 to 25 percent by 2010. Increases of this magnitude perhaps would present few problems in the Lake States and Cornbelt, where nitrate concentrations in water evidently are not now serious. The situation might be different, however, in the Northern Plains. As noted earlier, nitrate concentrations in groundwater in some parts of Nebraska now are about 20 ppm, twice the Public Health Service's standard for safe water. In such areas, the prospect of increased nitrate losses of 20 to 25 percent indicates cause for concern.

Our projections indicate large relative increases in nitrogen applied in the South, Southwest, Mountain Region and Pacific Coast. Even allowing for the spread of more efficient nitrogen materials and practices, the projections imply substantial increases in nitrate losses in these regions. Without information about present nitrate concentrations in regional water bodies, there is no basis for judging whether the increased losses would pose water quality problems. In our judgment, however, the increases are sufficiently large to indicate that such problems may emerge by 2010. The Southeast in particular would bear watching. Much of the expansion in crop production and fertilizer use in that region will be with irrigation on the sandy soils of Georgia and northwest Florida. The potential for increased leaching of nitrate-N to the groundwaters of the region looks large.

PESTICIDES

Nature of the Environmental Impacts

Pesticides are chemicals designed to kill various species of plants and animals considered to be pests by farmers and others. Their presence in the environment arouses concern because often they act not only against the target pests but also against other organisms. They may pose threats to human health and reproductive capacity; do damage to non-target species of plants, insects, soil and water microorganisms, and wildlife; and cause the build-up in pests, especially insects, of genetic resistance to pesticides.

Present Severity of the Problems

Pimentel et al. (1980) have estimated the total environmental costs of pesticide use in the United States at $839 million annually. This includes seven categories of environmental cost ranging from reduced natural enemies and increased genetic resistance to pesticices ($287 million) to fish and wildlife losses ($11 million). Human pesticide poisonings, including those that result in fatalities, are included ($184 million).

Pimentel et al. state that they were unable to estimate some important classes of environmental costs of pesticides. Had these been included, total costs would have been "several times" higher than those reported.

Total direct and environmental costs of pesticides are estimated by Pimentel et al. to be about $3.35 billion and total benefits to be $10.9 billion. Benefits exceed total costs by a factor of 3. If environmental costs are in fact three times as high as estimated by Pimentel et al., benefits exceed costs by a factor of 2.

Pimentel et al. are aware of the tenuous underpinnings of these estimates--indeed they emphasize them. We present the estimates here because to our knowledge they are the only ones available, and they are made by reputable scientists. Our presentation of the estimates does not imply endorsement of them. In fact we are skeptical that reliable estimates of environmental costs of pesticides are possible at present.

There are two reasons for our skepticism. One is the conceptual difficulty of valuing some of these damages, e.g., human deaths or genetic abnormalities, even in cases where the damages clearly are attributable to pesticides. Pimentel et al. assign a value of $1 million per life to the fatalities from pesticide poisoning, but they acknowledge that there is no really satisfactory way of valuing these losses.

The second reason for our skepticism is that little is known about the paths by which pesticides move through the environment and their ultimate fate, making it extraordinarily difficult to identify, let alone assign values to the damages they do. In the literature on environmental impacts of pesticides this second difficulty receives far more attention than the conceptual problem. For example, von Rumker et al. (p. 96) cite two comprehensive reports on environmental impacts of pesticides (Mrak, 1979; and Pimentel, 1971) as indicating

> ...that relatively little information is available on the toxicity and hazards of pesticides and their residues to non-target organisms under field conditions. Information is especially sparse concerning the effect, if any, of pesticide residues on lower aquatic and terrestrial organisms. There is a copious literature on the effects of individual pesticides on isolated organisms or systems in the laboratory or greenhouse over short periods of time. However, such studies are usually far removed from field conditions, and their results do not answer the question of their significance in regard to field conditions.

> ...Pesticide monitoring studies have centered on chlorinated hydrocarbon insecticides. The possibility that pesticides may affect terrestrial or aquatic ecosystems in other ways than through bioaccumulation and biomagnification has received less attention. By virtue of their physical, chemical, and biological properties, fungicides and herbicides are more likely to affect the lower trophic levels of food chains. It is not known whether or not currently practiced monitoring and observation methods would detect such effects prior to the occurrence of massive ecological damage.

In a more recent review of the literature dealing with the effects of pesticides on water quality, Wauchope (1978) concludes that, at least in principle, reasonable estimates can be made of edge-of-field losses of pesticides to rivers and lakes; however, information is most needed about the fate of pesticides after they leave the field. Wauchope argues (p. 471) that

> ...overall assessments of runoff impact must include judgments on such factors as the time and distance of impact of a given field runoff event and the ability of local ecosystems to recover from temporary high concentrations of a pesticide. The dynamics of dilution and sediment exchange, and uptake, transfer, and metabolism by aquatic life of most of the pesticides presently in use are not known. Without this knowledge, the impact of a given pesticide input or the quality of water in a river or lake cannot be predicted.

A convincing assessment of the current severity of the environmental impacts of pesticides thus is not possible. Consideration of some of the skimpy evidence about these impacts nonetheless is appropriate. We deal with insecticides and herbicides. These accounted for 86 percent of the pesticides applied to crops in 1976 (Eichers, Andrilenas, and Anderson). Fungicides, the principal other class of pesticide, are nontoxic or only slightly toxic to mammals. Consequently, in concentrating on insecticides and herbicides we miss little of significance concerning environmental impacts.

Insecticides--

The initial concern with insecticides was primarily with the effects of the organochlorine compounds, principally DDT and similar persistent materials, on wildlife and humans. While generally not highly toxic to vertebrates, the tendency of these materials to persist in the environment and to increasingly concentrate in body tissue at higher levels in the food chain made them suspect. When tests on laboratory animals indicated that, in high enough dosages, some of the organochlorine compounds were carcinogenic and/or teratogenic,[10] concern mounted still higher. Eventually, beginning with DDT in 1972, the EPA banned or tightly restricted the use of the organochlorine compounds, and by 1976 the only one still in general use was toxaphene. However, because of their persistence traces of these materials still are lurking about in the environment. To the extent that

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[10] Teratogenic materials cause fetal malformations.

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they pose a threat, the threat remains, although diminishing with time. If the threat includes cancer in humans--this is suspected but not conclusively demonstrated--the ultimate signs of it may not disappear for decades because of the long latency period of the disease.

We noted in the previous section that while the use of organochlorine insecticides has declined sharply since the early 1970s, use of organophosphorous and carbamate compounds increased enough to more than offset the decline. By comparison with the organochlorines these compounds are not persistent nor do they bioaccumulate. Unlike the organochlorines, however, many of the organophosphorous and carbamate compounds are highly toxic to humans and other nontarget organisms. Consequently the nature of the threat of these compounds is quite different from that of the organochlorines. Damages inflicted by the latter typically are subtle, diffused widely, both geographically and among affected individuals, and long-term. Damages of the organophosphorous and carbamate compounds typically are sharp, localized, and short-term. They in fact have many of the characteristics of industrial accidents rather than characteristics we typically associate with environmental impacts.

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According to Pimentel et al. (1980) there were fifty-two accidental deaths from pesticide poisonings in 1974, a significant decline over the preceding two decades. The number of intentional deaths (suicides and homicides) was about three times the number of accidental deaths. The total number of human poisonings from pesticides was estimated by Pimentel et al. to be about 45,000 per year. These were attributable to all pesticides, not just organophosphorous and carbamate insecticides.

and

One of the principal concerns with insecticides is the tendency for insects to build genetic resistance to these materials. When this happens farmers find themselves increasingly unable to control the resistant insect and crop losses mount. Increasing amounts of insecticide are applied, costs rise, damages to beneficial insects and other nontarget organisms increase, and resistance in the target insect is strengthened even more. Ultimately the insecticide may become completely useless and the farmer must fall back on a substitute, if one is available. Perhaps the outstanding example of the build-up of genetic resistance was the boll weevil's response to DDT. By the 1960s the insect had become so resistant that the use of DDT had begun to decline sharply some years before the EPA's action to ban it. The tobacco budworm and cotton boll worm also became resistant to DDT and subsequently to some of the more important organophosphorous compounds. Indeed, the increasing resistance of these insects gave major stimulus to development of nonchemical means of control of cotton insect pests in Texas, described in the previous section.

Since the mid-1970s use of synthetic pyrethroids to control cotton insect pests, particularly the tobacco budworm, has spread widely. The pyrethroids have low persistence--indeed their rapid rate of degradation may weaken their effectiveness--and low toxicity to mammals. They may be highly toxic to fish, but they are used in such small amounts and degrade so rapidly that the probability of a significant threat to aquatic life is small. The increasing adoption of synthetic pyrethroids by cotton farmers,

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therefore, has tended to ease the total impact of insecticides on the environment, especially to the extent that the pyrethroids have substituted for the highly toxic organophosphorous compounds.

Herbicides--[11]

Most herbicides have low toxicity to people. Paraquat, widely used with conservation tillage, is an exception. According to Giere, Johnson, and Perkins a dose of 10 to 30 mg/kg is fatal to half the human population, and continual contact in dilutions of 1 to 200 can cause skin irritation and loss or deformation of fingernails.

There is some evidence that a number of herbicides, including paraquat, may be carcinogenic or mutagenic. Giere, Johnson, and Perkins cite two studies, one of which raises a question about paraquat as a mutagen, and another which failed to find mutagenic activity. Chemical and Engineering News (April 11, 1980, p. 4) refers to studies in Europe indicating that 2,4,5-T and 2,4-D increase the risk of developing certain kinds of cancer. 2,4,5-T, the "agent orange" herbicide used in Vietnam for defoliation, is thought by some to also produce birth defects and other reproductive abnormalities. And the press has carried accounts indicting 2,4-D as the probable cause of miscarriages among women in Montana living in areas where 2,4-D was regularly used. Chemical and Engineering News, however, reports a study by the U.S. Government's National Toxicology Program of the effects of 2,4,5-T and 2,4-D on male mice showing no significant effect on fertility, reproduction, germ cell toxicology or survival and development of the offspring of the exposed animals.

Atrazine, which accounts for almost 25 percent of all herbicides applied to crops in the United States, most of it on corn, has low toxicity to humans. There is evidence, however, that atrazine may be transformed metabolically by plants to form a substance which is mutagenic (Plewa and Gentile). Giere, Johnson, and Perkins assert further that atrazine can be transformed in the human stomach to a nitrogen derivative under strong suspicion as a carcinogen.

A study by M. J. S. Hsia of propanil, another low toxicity herbicide used on rice, showed that in the soil propanil is metabolized by first fungi and then microorganisms to a compound very similar to dioxin, the teratogen found in Agent Orange (Science News).

Concern also has been expressed that extended application of herbicides may damage soil microorganisms. There is disagreement in the literature on this issue. Sommers and Biederbeck, after reviewing numerous laboratory and field studies, assert that herbicides (and insecticides), when applied at recommended field rates, generally have no lasting harmful effects on microbial populations in the soil.

Greaves appears to be in at least partial agreement with Sommers and Biederbeck. Summarizing a number of studies of the effects of herbicides on soil microorganisms Greaves states that "While there is some evidence

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[11] This section is taken from Crosson (1981).

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that changes in the soil microflora do occur following long-term use of herbicides, the data suggest that these changes do not necessarily result in significant changes in soil processes such as nitrogen transformation. Where processes do apparently change, this is generally ascribable to decreases in soil organic matter or to uptake of nutrients by surviving weeds" (p. 131).

Greaves does not take this conclusion as grounds for complacency, however. He points out that most of the work on the problem has ignored the effects of herbicides on microorganisms living on roots. Herbicides affect root morphology and may, therefore, damage these root dwelling microorganisms. Greaves ends by noting that relatively little is known about the long-term side effects of herbicides and calls for more research.

Eijsackers and van der Drift make a similar argument. They assert that while field tests show that soil fauna recover quickly from the toxic effects of herbicides, the processes underlying this are not well understood and "extensive research" is needed (p. 169). von Rumker et al. state that most studies of the metabolism and degradation of herbicides have focused on effects of herbicide residues in the soil on following crops or other valuable vegetation. Consequently there is little information about other effects of herbicide residues in the soil or in other elements of the environment.

There is enough uncertainty about the more subtle, long-term effects of herbicides on soil and water dwelling organisms, and perhaps on humans, to warn against complacency about present environmental impacts of these materials. Still, the available evidence does not support the argument that these impacts impose major environmental damage. This judgment is supported by a survey of thirty-six agricultural scientists from all around the country (Barnes et al.). The scientists were asked to describe cases of water pollution by pesticides which in their judgment constituted a problem. Only two problems clearly involving farm-applied herbicides were listed. Both were crop damage resulting from use of herbicide-contaminated water for irrigation. Picloram, a particularly persistent and leachable herbicide, has been found in the water of wells in two counties in Nebraska. The concentration was only a few parts per billion, but enough to damage crops irrigated with the well water. Similar damage was reported in cases where water from a pond contaminated by herbicides in runoff was used for irrigation, and where herbicide-contaminated runoff flows directly into fields.

The survey also brought mention of possible damage from atrazine and alachlor residues in sediment in the Chesapeake Bay estuary and in the Bay itself. A study suggested that these residues were killing bottom vegetation in the Bay. This is in dispute, however, because the scientific procedures used in the study are believed by some to be inadequate.

R. D. Wauchope, the person responsible for the survey of expert opinion about present pesticide damages to water quality, summed up his findings as follows:

> It is unlikely that any significant observable, nonpoint source water quality problem due to proper agricultural or silvicultural use of pesticides would not be known to at least one of the sources interviewed ...It is a reasonable conclusion,

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> then, that *with a few possible exceptions, currently-registered agricultural and silvicultural pesticides are not observed to be causing problems with respect to water quality*. (Barnes et al., p. 15. Emphasis in the original).

This conclusion must be taken with certain caveats. The experts surveyed by Wauchope did not address the possibilities that some herbicides, as noted above, may be carcinogens, mutagens or teratogens; and we already have seen that the absence of evidence that herbicides now constitute a major environmental threat may simply reflect the failure of researchers to look in the right places, or the inability of present detection techniques to pick up effects at very low trophic levels. Nevertheless, Wauchope's survey supports the judgment that, on the available evidence, present levels of use of herbicides do not pose major threats to the environment.

Future Severity of the Problems

The future environmental impacts of pesticides will depend upon the quantities of these materials used by farmers and upon their characteristics, particularly their toxicity and longer-term effects on humans and other nontarget organisms. We discuss both quantities likely to be used and characteristics.

Insecticides--

Judging from present quantities and nonpersistent characteristics of insecticides used, the environmental impacts of these materials are concentrated primarily in the Southeast and Delta and secondarily in the Cornbelt. This reflects the location of cotton production in the Southeast and Delta and the difficulty of controlling cotton insect pests in those regions, and the need to control corn insect pests, particularly the corn rootworm.

We concluded from our analysis in the last section of trends in technologies for controlling cotton and corn insect pests and of the continuing shift of cotton production from the Delta to Texas that the quantity of insecticides applied to cotton and corn would decline sharply from present levels. These crops are so dominant in total insecticide use that their decline would bring a significant reduction in the total quantity of insecticides used unless there were an extraordinary increase in amounts used on other crops. Our analysis of trends in insect management technologies for wheat pointed to no such increase. On the contrary, these trends are toward diminishing per acre applications of insecticides. While our projection of land in wheat indicates an offsetting trend, the prospect, in our judgment, is for little if any increase in total insecticide applications to wheat.

We projected a more than 100 percent increase in insecticide use on soybeans because of a relative shift of soybean acreage to the Southeast and Mississippi Delta. This increase is small in absolute amount, however, compared to the anticipated decline in insecticides used on cotton and corn.

The implication is that so far as the environmental problems of insecticides are a function of quantities used, the problems should diminish significantly, both from the national perspective and from the perspective of the three most affected regions.

We expect the characteristics of insecticides also to change in ways tending to diminish environmental damage. The shift away from the organochlorine compounds appears permanent, indicating that the particularly troublesome problems associated with persistence, biomagnification, and bioaccumulation will continue to decline.

The substitution of the organophosphorous and carbamate compounds for the organochlorines substitutes problems of acute toxicity for those of persistence, biomagnification, and bioaccumulation. To the extent that human mortality and morbidity are measures of environmental impact, this substitution would appear to be for the worse. While this appears a plausible presumption, such data as are available--and they are quite incomplete--do not indicate an increase in insecticide-related deaths associated with the shift to organophosphates and carbamates (National Academy of Sciences, 1975, pp. 87-89). Indeed, as noted earlier, the number of accidental deaths from pesticide poisonings was less in 1974 than two decades previously, the period when the shift from the organochlorines to organophosphorous and carbamate compounds was occurring (Pimentel et al., 1980).

The shift away from the organochlorines may also have reduced water pollution by insecticides. Pimentel et al. cite three studes of pesticide concentrations in surface waters of the United States which show a steady decline in concentrations from 1964 to 1978. Total pesticide use increased sharply in this period. Pimentel et al. attribute the decline in concentrations to the shift from the persistent organochlorines to the less persistent organophosphorous and carbamate compounds.

There is another, perhaps subtle, respect in which the shift to the organophosphorous and carbamate compounds may be favorable to the environment. Injury to humans and other nontarget organisms by these materials result from their acute toxicity, meaning that the injury is severe and quickly evident. Consequently, both the victims and those responsible usually can be readily identified. The damages caused by the organochlorine compounds--by contrast, do not produce sudden, severe symptoms, but rather show up as impaired reproductive processes, cancer, or other long-delayed effects. In addition, because of the persistence, biomagnification and bioaccumulation properties of the organochlorines, it may be difficult if not impossible to determine the original source of the damaging materials and those responsible for them. Because of these differences in the timing and nature of the damages done, the organophosphorous and carbamate compounds likely would be easier to manage than the organochlorines. The point is not that the *potential* environmental damages of the organophosphorous and carbamate compounds are less--they may in fact be greater--but that the actual damages may be less because of greater ease in management of these materials.

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The substitution of synthetic pyrethroids for some of the organophosphorous compounds in control of cotton insect pests seems likely to continue. Since the pyrethroids have low toxicity to mammals and are not persistent, this trend reduces pressure on the environment. Their apparent high toxicity to fish is offset by the low probability that they will reach surface waters in significant amounts. There are reports from the Southwest of emerging resistance of the tobacco budworm to the pyrethroids, and if this becomes general the usefulness of these materials will be greatly reduced. If this happens, however, it would appear to be five to ten years ahead, time in which to develop substitutes for the pyrethroids. While we do not now foresee what these substitutes may be, the whole thrust of research and development in cotton pest management technologies is toward substitution of nonchemical for chemical means of control. We consider it unlikely, therefore, that whatever substitutes for pyrethroids are developed--if indeed they become necessary--will pose a greater threat to the environment than the pyrethroids.

We conclude that on balance changes in characteristics of insecticides will reinforce the prospective decline in amounts applied to significantly reduce the environmental damages of insecticides over the next several decades.

Herbicides--

We concluded in the previous section that if per-acre amounts of herbicides applied to land in corn, wheat, soybeans, and cotton remain the same as in 1976, total herbicide applications to these crops (82 percent of all herbicides applied to crops in 1976) would rise 21 percent from 1976 to 1985 and 53 percent to 2010 (see Table 5-15). We also noted that if conservation tillage spreads to 50 to 60 percent of cropland by 2010, as seems likely, the increase in total herbicide use would be significantly higher than these numbers indicate.

5-15

While the shift to conservation tillage will increase the amounts of herbicides applied more than otherwise would occur, the movement of herbicides from farmers' fields probably will not rise in proportion to the increase in amount of herbicides. The reason is that losses of herbicides through erosion and runoff probably are less with conservation tillage than with conventional tillage. This is the conclusion of a survey of the literature on tillage and losses of pesticides by Wauchope, McDowell and Hagen. It was the key finding also of a study of small watersheds in Iowa by Baker and Johnson.

Despite the apparent favorable effect of the shift to conservation tillage in reducing herbicide losses, the projected increase in amounts applied in 2010 is so large that a significant increase in the quantity of herbicides in the environment is implied. To the extent that quantity is a measure of environmental burden, that burden would increase.

The issue of the inherent threat of herbicides to the environment thus is crucial in judging the severity of the future threat. We concluded from our previous discussion of the issue that the evidence does not support the

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inference of a major inherent threat. We noted, however, that some aspects of the herbicide-environment relationship which may contain a threat have not been thoroughly investigated. The possibility of real or potential threats, therefore, cannot be discounted. Moreover, we have no experience with the use of herbicides on the scale projected for 2010. Conceivably there could be thresholds of environmental damage which expansion on the projected scale would pass.

The possibilities of presently undetected or potential future environmental damages of herbicides are sufficiently likely, in our judgment, to justify intensive, continuing investigation of herbicide-environment relationships, and a wary attitude toward the expanding use of herbicides. Adopting such an attitude, we nevertheless conclude that present knowledge does not suggest that the projected expansion of herbicide use will pose a major threat to the environment.

IRRIGATION

6-1/2"

Nature of the Environmental Impacts

Irrigation may, and in arid areas typically will, lead to an increase in soil salinity. Where water is used several times for irrigation, as river water usually is, the salt content of the water also rises. Too much salt in the soil or in irrigation water inhibits plant growth, and in extreme cases may render the land and water useless for agriculture.

9-1/8"

All water used for irrigation carries salts. The increasing concentration of salt in the soil occurs because of evaporation of some of the water applied to the land. Over time the amount of the salt will increase unless it is periodically flushed out by rain or by water applied specifically for that purpose. Flushing of the salt will protect the productivity of the land so cleansed, but it increases the salt content of the water available to farmers downstream. The salt content of the water also increases as it moves downstream because irrigation return flows carry salt from the land to the river.

If drainage is inadequate, repeated irrigation may also raise the underground water table within reach of the plant root zone. Capillary action then will carry water close to the soil surface where it evaporates, leaving a salt residue. The accumulation of these residues eventually will reduce the productivity of the land.

Stream flow is reduced by withdrawals of river water for irrigation. The decline in stream flow increases pollutant concentrations and water temperature. Both can have devastating effects on riverine flora and fauna. Moreover, the flow of fresh water into estuaries and tidal marshes is diminished, reducing the productivity of these ecologically vital and often commercially valuable resources.

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Irrigation may increase erosion relative to pre-irrigation treatment of the land. It may also have the opposite effect, however, by increasing the plant cover of the land, thus reducing its exposure to the erosive effects of wind and rain.

Because irrigation increases the productivity of the land compared with dryland farming it justifies greater per-acre use of fertilizer and pesticides, thus increasing the likelihood of environmental damage from these materials.

Present Severity of the Problems

Salinity is the most pervasive environmental problem stemming from irrigation in the United States.[12] Except for the Columbia, all western river basins are confronted with high and generally rising salt levels. In much of the Lower Colorado, parts of the Rio Grande, and the western portion of the San Joaquin river basins, the salt concentrations in either the water or the soils are approaching levels that threaten the viability of traditional forms of irrigated agriculture. Groundwater salinity is not now a widespread problem in the West, However, the problem is growing and already is serious in parts of California, New Mexico, Montana, and Texas (U.S. Department of Interior, April 1975, pp. 116-118, and U.S. Water Resources Council, Vol. I, Summary, p. 65). Although groundwater is less susceptible than surface waters to pollution, the clean-up of groundwater is difficult.

von Schilfgaarde estimates roughly that 25 to 35 percent of the irrigated lands in the West have some type of salinity problem, and that the problems are getting worse.[13] Salinity already is a serious problem in two large irrigated areas, the Lower Colorado River Basin and the west side of the San Joaquin Valley in California. The underlying cause of the problem in the two areas differs. In the Colorado the salt content of the river increases progressively downstream due to the salt-concentrating effects of irrigation and the addition of salts picked up as the water passes over saline formations. About two-thirds of the salts delivered to the Colorado are from natural sources. Elimination of these deliveries would require expensive investments to divert the river and its tributaries around some of the areas contributing the salts. Irrigation accounts for most of the remaining salts. These could be curtailed greatly by reducing irrigation return flows. Annual damages from salinity in the Colorado River were estimated between $75 and $104 million in 1980. (U.S. Department of Interior and U.S. Department of Agriculture, 1977).

In the San Joaquin Valley the principal salinity problem occurs because poor drainage prevents salt-laden waters from being carried away from the fields. High water tables already threaten the productivity of about 400,000

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[12] This discussion of salinity in the West is taken from Frederick (1981), Chapter 6, pp. 6-5/6-7.

[13] Jan van Schilfgaarde, Director, U.S. Salinity Laboratory, Riverside, California, in an interview with Kenneth Frederick, February, 1980.

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acres. Ultimately more than 1 million acres in the Valley may be similarly affected. A $1.26 billion drainage system has been proposed to carry irrigation runoff from the western side of the Valley to the Sacramento Delta. Because farmers would have to install their own underground drainage to get the waters to the central drain, the total costs of an effective system would be considerably higher than $1.26 billion (U.S. Department of Interior, California Department of Water Resources and California State Water Resources Control Board).

Salinity induced by irrigation is overwhelmingly a problem of the arid and semiarid West. It is not a significant problem in the principal irrigated areas of the East: the Mississippi Delta region, the Great Lakes states and the Southeast.

The contribution of irrigation to the nation's erosion problem is minor. Although erosion and sedimentation are viewed as problems in many areas of the West, it is not clear, with a few exceptions, that irrigation is an important contributor to these problems. A report by the U.S. Department of Interior (April 1975, p. 127) states that in the eleven most western states "most of the rapidly eroding range, grassland, and forest-covered soils occur where natural geologic erosion is dominant." The human contribution to erosion probably has been more important in the Plains States, but the contribution there of irrigation is mixed. Center pivot irrigation is important in that region, and the wheel tracks left with this system can lead to gully erosion. However, erosion by wind is far more important than erosion by water in the West, and irrigation, by increasing ground cover, helps to contain wind erosion. The National Resources Inventory showed that soil loss from wind erosion on cropland in the ten Great Plains states was 893 million tons in 1977, or 5.3 tons per acre (USDA, Aug. 21, 1979 and Feb. 1980). Erosion by sheet and rill erosion (that is, by water) in these states was 516.6 million tons, or 3.1 tons per acre. Only a small part of the sheet and rill erosion was caused by irrigation, rain being the dominant cause. The Soil Conservation Service sets 3 to 5 tons per acre per year as the maximum amount of soil loss consistent with maintaining the productivity of the land indefinitely. By this standard we can conclude that irrigation in the West does not contribute importantly to the region's erosion problem. Indeed, the NRI data suggest that erosion of cropland by water, whatever the source, may not be a problem in the West.

We point out below that sheet and rill erosion is a major problem in parts of the East, including parts of the Mississippi Delta and the Southeast, the principal areas of irrigated farming in the East. However, in those states where erosion is particularly serious--Mississippi, Alabama, and Georgia--less than 10 percent of cropland is irrigated, and there is no reason to believe that irrigated land contributes more erosion per acre than nonirrigated land. Indeed, except when sprinkler systems are used, irrigation typically requires that the land be leveled, suggesting that irrigation would reduce erosion from such land.

The Second National Water Assessment (U.S. Water Resources Council) identifies agricultural chemicals as a "significant" source of surface water pollution in three areas in the West, but does not indicate whether irrigated or dryland farming is the principal culprit. In comparison with the rest of the country this problem is not very extensive in the West. In our earlier discussion of fertilizer pollution we noted certain "hot spots" in southern California where nitrates in groundwater are perceived to be a problem, with irrigation a probable contributor. We also noted nitrate levels of 20 to 25 ppm in groundwater in the Sandhills region of Nebraska, where irrigation is extensively practiced. However, in other parts of the Plains states that have been under irrigation for many years, e.g., the High Plains of Texas, there still are no observable problems of groundwater pollution from irrigation.

The Assessment indicates that agricultural chemicals present more water quality problems in the East than in the West. However, since only a small percentage of cropland in the East is irrigated, the contribution of irrigation to these problems, such as they are, must be correspondingly small.

Future Severity of the Problems

We expect only limited further expansion of irrigation in the West, so we do not expect the addition of irrigated land to significantly increase the environmental damages of irrigation. However, the severity of the major source of damage, salinity, is not just a function of the amount of irrigated land. Salinity tends to increase on a given amount of land with repeated irrigations. The salinity problem, therefore, is likely to increase more than in proportion to the increase in irrigated land unless steps are taken to deal with it. According to Frederick, improved farm management techniques can go a long way toward reducing some salinity problems and obviating the need for some of the costly structural solutions under consideration.[14] Efficient water and agronomic management reduces evaporation losses, permitting achievement of given yields with less water. The reduction in water applied and evaporation slows the buildup of salt concentrations in the soil. In addition, agricultural scientists have developed crops and irrigation techniques which enable farmers to irrigate successfully with surprisingly high salt levels. For example, van Schilfgaarde (1977) reports research suggesting that salinity in the lower portion of the root zone can be permitted to build up considerably more than suspected without decreasing yields if good quality water is applied in the upper zone. Science has made and is likely to continue to make breakthroughs such as the development of crop varieties with higher tolerance to salt, which will expand the possibilities for successful irrigation with saline water and soil. While such results may postpone or mitigate the damages of high salt buildup, the long-term implications of rising salt levels are uncertain. The soils can be used in the short term as a depository for salts, but eventually additional salts would have to be flushed to preserve productivity.

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[14] This discussion of techniques for managing salinity is based on Frederick (1981), Chapter 6, pp. 6-16/6-17, as modified on the basis of comments by Jan van Schilfgaarde. van Schilfgaarde is not responsible for the analysis here presented.

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Improved basin-wide water management also has great potential for reducing salinity problems. Where poor drainage prevents salt-laden waters from being carried away from the fields, artificial drainage is required to prevent eventual loss of productivity. But the extent of the drainage needs can be greatly reduced through good management. van Schilfgaarde suggests that the San Joaquin Valley drainage problem could be reduced to about 5 percent of current levels and a long-term equilibrium reached through an integrated irrigation system whereby the best water is used first on salt-sensitive crops with the increasingly salt-laden runoff applied to increasingly salt-tolerant crops. The remaining highly saline waters would be reduced to quantities that could be disposed of in evaporation ponds rather than requiring a costly trans-basin drain.[15]

We concluded above that irrigation does not contribute importantly to erosion at present, and we do not expect this to change over the next several decades. Part of the considerable increase in fertilizer applications we project for the Southeast, however, is associated with the prospective expansion of irrigation in that region (see Section 4). Environmental impacts of much of the additional irrigation in the Southeast will be on sandy soils in Georgia and Florida where percolation rates are high. The expansion of irrigation in that region, therefore, likely will contribute to increasing nitrate concentrations in groundwaters of the region. We are unable to say, however, whether the concentrations are likely to reach troublesome levels.

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EROSION

Nature of the Environmental Impacts

There are two sorts of impacts: on-farm and off-farm. The on-farm impact is the socially undesirable loss of productivity resulting from erosion of topsoil.[16] The topsoil supports plant growth by providing storage for nutrients, moisture and air, and a medium in which plant roots can take hold. Erosion will eventually reduce the capacity of the topsoil to provide

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[15] van Schilfgaarde in an interview with Kenneth Frederick, February 1980.

[16] The socially undesirable productivity losses imposed by erosion perhaps should not be called environmental costs as those costs are usually defined. Environmental costs typically mean damages inflicted on society by effluents of production and consumption activities. The social costs of productivity losses are in higher prices of food and fiber reflecting a divergence between the social and private interest in maintaining the productivity of the land. However, dealing with the social costs of erosion-induced productivity losses poses an issue of public policy in precisely the same sense as the off-farm damages of erosion, which are "environmental" in the usual sense of the word. Hence we treat the productivity losses as a kind of environmental cost.

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these services to the plant unless new soil is formed at a rate sufficient to offset erosion losses. The rate at which new soil is formed is highly variable, depending upon the nature of the parent material underlying the topsoil, climate, biological factors (plants, soil flora and fauna) and topography (Cady, 1980). The U.S. Soil Conservation Service (SCS) has defined the tolerable level of soil loss ("T" value) as the maximum amount of loss per acre per year "that will permit a high level of crop productivity to be sustained economically and indefinitely" (Wischmeier and Smith, p. 2). Both physical and economic factors are considered in establishing "T" values, although Wischmeier and Smith's discussion suggests that physical factors are dominant. They assert, for example (p. 2), that "T" values in the United States range from 1 to 5 tons per acre per year, depending upon soil properties, depth, prior erosion, and topography. Five tons of topsoil is about one-thirtieth of an acre inch, suggesting that in the judgment of the SCS that is the maximum amount of new soil that can be formed in a year in most circumstances.

It is important to note that erosion-induced losses of productivity *per se* do not impose on-farm environmental costs. Only those losses which impinge on society's interest in the productivity of the land are counted. These losses arise when there is a divergence between society's interest and the farmer's interest in this respect. Society's interests include those of future generations, but it is difficult for these interests to be registered in ways that will make the farmer responsive to them. The farmer's concern about erosion is strongly conditioned by his expectations about future crop prices relative to current prices. Since the prices at which American farmers sell are highly unstable, the prudent farmer will apply a high rate of discount to future prices. The effect is to shorten his planning horizon. If current prices are high he will farm his land intensively, abandoning soil conservation practices if necessary, because the future beyond the next year or two is highly uncertain.

If commodity and land markets correctly measured the long-term social interest in maintaining the productivity of the land, then the effect of erosion on that interest would be reflected in land prices. Farmers who did not hold erosion within socially acceptable limits would find the value of their land reduced. They would have incentive, therefore, to take the measures necessary for erosion control. However, that markets correctly measure the social interest in maintaining the productivity of the land is questionable. Markets do not register prices expected to prevail generations into the future. The reason is not simply that those who will people future generations are not yet born or are too young to express their interests. The fundamental difficulties are vast uncertainty about the substance of the interest of future generations in conserving the land and about how best to serve that interest, even if it were clearly identified. How big will future generations be, and how much income will they have? How much of it will they spend for food and fiber, and how can these demands be modified, without damage to welfare, if they appear to exceed the capacity of the land to meet them at reasonable cost? What are the possibilities for substituting other inputs or techniques, e.g., fertilizer, increased photosynthetic efficiency, hydroponic farming, for the land in meeting these demands?

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Fundamentally, it is the great uncertainty surrounding answers to these questions which leads to a divergence between the farmer's interest and society's interest in conserving the land, hence to socially undesirable amounts of erosion. But if the uncertainty is so great, how can we be sure that there is a conflict between the social interest and the farmer's interest in the land? The fact is we cannot be sure. We can reasonably expect, however, that the combination of rising world population and income will substantially increase future demands for American produced food and fiber; that continued erosion will diminish the capacity of the land to meet these demands; that compensating technological advance is uncertain, and that if it fails the resulting increase in costs of food and fiber may produce significant social problems in the United States and in other countries where U.S. interests are involved. We can be reasonably sure that the rise in food and fiber prices would not be signaled to the farmer far enough in advance to induce him to take action to reduce erosion. It appears, therefore, that for society, the prudent course is to assume a likely divergence between the public interest and the farmer's interest in maintaining the productivity of the land.

The off-farm costs of erosion result from the sedimentation of reservoirs and lakes, rivers, and harbors, and from the need to process the water to make it drinkable or usable for industrial purposes. The suspended sediment reduces recreational values provided by water and may injure fish populations. When the sediment settles it shortens the useful life of reservoirs for generation of power and in providing irrigation and flood control, and of harbors in all the manifold services they provide. Removal of the sediment from these water bodies becomes a continuing and costly burden.

In thinking about both the on-farm and off-farm costs of erosion it should be remembered that some of the world's most productive land is in flood plains built up by soil moved by water from upstream. We should be grateful for the existence of such land, but also recognize that most of it was put in place at a time when the social cost of the process was low. Under present conditions, building the productivity of the land by downstream deposition of eroded soil has got to be socially more costly than preserving the productivity of the land threatened by erosion.

Present Severity of the Problems

It is quite certain that the productivity of the nation's agricultural land has been and is being reduced by erosion. There are no reliable, comprehensive estimates of past or current productivity losses, however. Whatever past losses may have been, advances in technology more than compensated for them. Production of crops per acre of cropland increased 110 percent from 1910-14 to 1975-79, an annual rate of 1.14 percent. The rate of increase was especially rapid after World War II: 1.83 percent.

This is not to say that the erosion-induced losses were, or are, negligible from a social standpoint. Since by definition these losses do not enter the farmer's private calculations, they probably did not get the weight society would have given them. Had this weight been assigned, the

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pattern of output growth likely would have veered more toward preserving productivity by reducing erosion and less toward finding technological substitutes for the land.

All of this, however, is speculation. As noted earlier, the possibility of divergence between the farmer's interest and society's interest in preventing losses in productivity of the land is sufficiently great to justify the presumption that the losses are excessive.

There are conflicting estimates of erosion from agricultural land, implying conflict also in estimates of the off-farm costs of this erosion. Pimentel et al. (1976) cite various sources indicating that costs of dredging rivers and harbors, of reduced useful life of reservoirs, and of other sediment damages came to about $500 million annually in the 1960s. In 1980 prices these costs probably would not be less than $1 billion.

These costs reflect total erosion, not just that from agricultural land. Pimentel et al. estimated total water-borne sediment at 4 billion tons per year, three-quarters of it from agricultural land. Meister et al. use figures which imply substantially smaller amounts of water-borne sediment from agricultural land than estimated by Pimentel et al. In contrast, estimates from the NRI (USDA, Feb. 1980) indicate that the Pimentel figures may be low.

Clearly there is great uncertainty about present on-farm and off-farm environmental impacts of erosion. Nevertheless, consideration of current rates of erosion provide some insights to the present severity of the problem. Since in this study we are interested in the environmental impacts of crop production, we focus on erosion from cropland.

Table 6-1 shows national and regional estimates of erosion from cropland in 1977. For the nation, total erosion was 2,799 million tons, about two-thirds of it sheet and rill erosion and one-third erosion by wind. Sheet and rill erosion accounted for a little more than two-thirds of the 6.8 tons per acre of total erosion. Sheet and rill erosion also was important on rangeland, pasture, and grazed forestland (figures not shown in Table 6-1), but per-acre loss rates were significantly lower in those cases. Moreover, the heaviest losses occurred in less populated areas and on less valuable land, making their economic costs and damages to the human environment clearly less significant. Cropland erosion losses, by contrast, were concentrated in such productive states as Iowa, Illinois and Missouri (parts of the Cornbelt), Nebraska and Kansas (parts of the Northern Plains); Tennessee and Kentucky (parts of Appalachia); and Mississippi and Alabama (parts of the Mississippi Delta). Thus, the agricultural heartland of the country is most severely affected.

In the Great Plains, cropland also is subject to significant wind erosion. Texas, New Mexico, and Colorado are most vulnerable, with losses amounting to 9 to 15 tons per acre in those states. Indeed, wind erosion from cropland in Texas accounts for 16 percent of total cropland erosion in the entire nation. In Plains states other than Texas, New Mexico and Colorado, wind erosion rates fall below 5 tons per acre for all cropland.

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Table 6-1. EROSION FROM CROPLAND IN THE UNITED STATES

	Wind		Sheet & Rill		Total		Percent of Total	
Region	Amount (mil.tons)	Tons per Acre	Amount (mil.tons)	Tons per Acre	Amount (mil.tons)	Tons per Acre	Erosion	Cropland
Nation	891	2.1	1,908	4.7	2,799	6.8	100	100
Northeast	n.e.		82.9	5.0	82.9	5.0	3.0	4.0
Lake States	n.e.		117.5	2.7	117.5	2.7	4.2	10.7
Cornbelt	n.e.		688.3	7.7	688.3	7.7	24.6	21.8
Iowa	n.e.		261.3	9.9	261.3	9.9	9.3	6.4
Northern Plains	212.3	2.2	322.4	3.4	534.7	5.6	19.1	22.9
Nebraska	25.9	1.3	117.8	5.7	143.7	7.0	5.1	5.0
Appalachia	n.e.		186.3	9.0	186.3	9.0	6.7	5.0
Tennessee	n.e.		69.5	14.1	69.5	14.1	2.5	1.2
Southeast	n.e.		111.0	6.3	111.0	6.3	4.0	4.2
Georgia	n.e.		42.7	6.6	42.7	6.6	1.5	1.6
Delta	n.e.		154.9	7.3	154.9	7.3	5.5	5.1
Arkansas	n.e.		46.7	5.9	46.7	5.9	1.7	1.9
Southern Plains	488.8	11.6	141.4	3.4	630.2	15.0	22.5	10.2
Texas	453.5	14.9	99.5	3.3	553.0	18.2	19.6	7.4
Mountain	190.3	4.5	70.8	1.7	261.1	6.2	9.3	10.2
Pacific	n.e.		31.9	1.4	31.9	1.4	1.1	5.6
California	n.e.		8.6	.9	8.6	.9	.3	2.4

Note: n.e. means not estimated.

Source: USDA (Feb. 1980 and 1980). The data are for the 48 contiguous states. When Hawaii and the Caribbean area are included, total sheet and rill erosion is 1,926 million tons.

Sheet and rill erosion are caused by water. Sheet erosion is the movement of continuous layers of soil from the field. If the water moves fast enough it scours the soil and cuts small channels in the soil surface. The soil moved in this fashion is rill erosion.

The trend in erosion loss is difficult to assess. SCS surveys in 1958 and 1967 showed somewhat higher average losses from sheet and rill erosion than the NRI and a greater percentage of cropland needing conservation treatment. However, there are judgment factors involved in arriving at these numbers, and it is difficult to know if they were treated in precisely the same manner two decades apart. Even with this caveat in mind, it is useful to note that reported erosion losses dropped about 1 ton per acre and the amount of cropland needing conservation treatment fell by 3 percentage points between 1967 and 1977--a period when the reserve of idle and often erosion-prone acreage was brought back into cultivation and many decried the apparent increase in erosion (USDA, 1974, USDA, February 1980). This reported improvement in the face of greater cropping pressure coincided with a significant spread in the use of conservation tillage during the same period.

At the national level, sheet and rill erosion losses from cropland approach the maximum of 5 tons per acre per year set by the SCS as consistent with long-run maintenance of the productivity of the land, and erosion by wind and water combined exceed the limit.

These national soil loss averages conceal more severe local and regional problems. Many states, especially in the West and Lake states, have low average losses from cropland, while in parts of the Cornbelt, Delta, Southeast, and Wouthern Plains, losses far exceed tolerable amounts. But erosion is a still more localized problem. It may be severe in very small areas or on individual fields or parts of fields, even in regions that generally are not afflicted. Nationally, 10 percent of the cropland accounts for 90 percent of all sheet and rill erosion in excess of 5 tons per acre (USDA, 1980, Part II). Because the problem tends to be localized, it is amenable to sharply focused programs of control, discussed in the next section.

The soil moved by wind and water erosion carries organic matter and nutrients from the field. Erosion losses from the top layers of soil usually are the most damaging to soil quality because they are richest in the nutrients and organic matter that are most accessible to plants. Damage on the field can be measured in terms of the costs of replacing the nutrients lost and the possible decrease in the productive potential of the land once erosion exceeds "T" value. There are no confident measures of either effect. The RCA study concluded that erosion at 1977 rates would reduce potential corn and soybean yields in the Cornbelt by 15 to 30 percent over a fifty year period (USDA, 1980, Part II). Other studies suggest that these figures may be conservative. This does not necessarily mean that yields will decline, but the land will become less responsive to other inputs and will require more of them to sustain any given level of output.

The RCA estimates suggest that indefinite continuation of present rates of erosion will in time impair the productivity of the land enough to increase costs of agricultural production. Since trends in prices and productivities of nonland inputs also suggest rising costs, the additional impetus to costs given by erosion is not to be taken lightly. In addition, as we already have seen, estimates by Pimentel et al. (1976) indicate that off-farm erosion damages to lakes, reservoirs, and harbors probably are not less than $1 billion per year in 1980 dollars. There is basis for believing,

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therefore, that the on-farm and off-farm environmental impacts of present rates of erosion are cause for concern. Given our projections of production, land use and technology, what can we say about future impacts?

Future Severity of the Problems

To obtain insights to future environmental impacts of erosion we engaged the help of the Center for Agricultural and Rural Development at Iowa State University. Specifically, we asked the Center to run our projections to 2010 of land in feedgrains, wheat, soybeans, and cotton through the ISU model of the U.S. agricultural economy to obtain projections of erosion.[17] The results are shown in Table 6-2. A description of how the results were obtained will be useful for interpreting them. We provided ISU with an initial set of projections to 2010 of harvested land in feedgrains, wheat, soybeans, cotton, hay, and fallow, for the nation and the ten USDA producing regions. The projections were fed into the model and the result was the set of projections of erosion called run 1 in Table 6-2. (The model yields many other outputs, but our interest was in erosion.) As indicated in Section 4, the model is structured to give results by the 19 river basins shown in the table rather than by the ten USDA producing regions. Moreover, the model had difficulty in accommodating the RFF projections of harvested land precisely as we had prepared them, so the run 1 results reflect a slightly different cropping pattern than the one we had projected. There was no difference in the land totals, however.

The ISU model allocates land and production by three kinds of tillage technology and four kinds of conservation practices. The tillage technologies are (1) fall plowing with the moldboard plow, residue removed (here called conventional tillage); (2) spring plowing, with or without the moldboard, with residue left until spring (here called low conservation tillage); (3) spring plowing with something other than the moldboard, with residue left year around (here called high conservation tillage). The four conservation practices are straight row planting, contour farming, stripcropping and terraces, each of which may be practiced with any of the tillage technologies.

Given projections of production, the model chooses among tillage technologies and conservation practices so as to minimize production costs. In run 1 the model allocated 17.2 percent of harvested land to conventional tillage and 82.8 percent to the two forms of conservation tillage, 34.9 percent to the "low" form and 47.9 percent to the "high" form.

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[17] As noted in footnote 3, Section 4, the ISU model is a cost minimizing linear programming type. It permits analysis of a variety of resource and environmental issues touching U.S. agriculture from both regional and national perspectives. The model was used extensively by the USDA in its RCA work to explore the implications of various scenarios about future levels of agricultural production and policies for controlling erosion.

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Table 6-2. PROJECTIONS OF SHEET AND RILL EROSION FROM CROPLAND IN THE UNITED STATES IN 2010

	Run 1		Run 2	
	Total (mil.tons)	Per Acre (tons)	Total (mil.tons)	Per Acre (tons)
Nation	2,320	5.2*	3,537	8.3*
New England	2.6	3.3	1.5	2.2
Mid-Atlantic	123.9	10.6	121.5	10.7
South Atlantic-Gulf	465.6	13.5	435.9	16.9
Great Lakes	50.5	2.0	83.2	3.4
Ohio	152.2	4.0	357.6	9.4
Tennessee	48.1	8.5	52.6	15.2
Upper Mississippi	284.7	4.1	617.8	9.0
Lower Mississippi	217.1	8.7	398.3	17.8
Souris-Red-Rainy	52.1	2.7	48.0	2.6
Missouri	257.9	2.6	559.8	5.5
Arkansas-White-Red	287.9	5.5	408.8	7.8
Texas Gulf	262.8	8.6	336.7	11.8
Rio Grande	20.0	5.6	13.7	5.2
Upper Colorado	2.0	1.3	2.5	1.6
Lower Colorado	.8	.6	.3	.5
Great Basin	2.4	2.0	6.4	4.2
Columbia-North Pacific	85.2	4.9	88.2	5.2
California-South Pacific	4.4	.6	4.3	.6

Source: Runs of Iowa State University model of the U.S. agricultural economy done for this study. The regions are the river basins draining the 48 contiguous states.

*The estimates of erosion per acre exclude 48 million acres of cropland not treated in the ISU model. When this land is included, as it should be to make these estimates comparable to those in the NRI, per acre erosion from cropland is 4.7 tons in Run 1 and 7.4 tons in Run 2.

Table 6-3. SEDIMENT DELIVERED TO WATER BODIES IN THE UNITED STATES (mil./tons)

Region	1977	2010 (Run 2)
Northeast	26.6	39.2
Lake States	45.7	93.0
Cornbelt	250.9	319.9
Northern Plains	141.7	246.5
Appalachia	57.7	139.4
Southeast	41.9	101.2
Delta	73.8	175.1
Southern Plains	69.3	256.4
Mountain	29.5	48.3
Pacific	11.2	30.8
Nation	748.3	1,449.8

Source: Prepared for this study by Leonard Gianessi of Resources for the Future, based on data and procedures developed in Gianessi, Peskin, and Poles. Sediment delivered in each region is estimated by multiplying gross erosion in each region by estimates of sediment delivery ratios.

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Our analysis of tillage technologies led us to conclude that by 2010 some 50 to 60 percent of cropland would be in some form of conservation tillage. Thus the model's projection of 83 percent appeared high to us. This view was reinforced by the knowledge that the model takes account of the long-run effects of erosion on crop yields, a characteristic favoring conservation tillage over conventional tillage in scenarios projected several decades into the future. We think it probable that farmers give less weight to the long-term effects of erosion than the model does. We were particularly skeptical of the high percentages put in conservation tillage by run 1 of the model in the Ohio basin (86 percent) and the Upper Mississippi basin (98 percent). Our analysis of tillage technologies suggested that in much of the Ohio basin soils are too moist to support such a high percentage of land in conservation tillage and much of the Upper Mississippi region (which includes most of Minnesota and Wisconsin in addition to most of Iowa and Illinois) too cool soil temperatures in the spring would be similarly limiting.

For these reasons we asked ISU to make a second run of the model, using the same projections of production and land use as in run 1, but with two changes in other respects: (1) let the model allocate production by region, and (2) impose upper limits on the amount of land that could be in high conservation tillage of 60 percent in the Ohio basin and of 70 percent in the Upper Mississippi. In all other regions the model was free to allocate land among tillage technologies in accordance with its cost minimizing principle.

As Table 6-2 shows, the second run of the model projected substantially more erosion, both in total and per acre, than the first run. This occurred even though the total amount of land in crops was less than in run 1 by 17 million acres (4 percent) and the amount of land in some form of conservation tillage was the same as in run 1, 83 percent. The difference was that the amount of land in high conservation tillage fell from 48 percent in run 1 to 31 percent in run 2. In the Ohio basin land in high conservation tillage fell from 86 percent to 47 percent, even though a maximum of 60 percent was permitted. In the Upper Mississippi high conservation tillage fell from 98 percent to 62 percent, less than the permitted maximum of 70 percent.

to 47 percent

We consider run 2 of the ISU model to be more consistent than run 1 with our analysis of tillage technologies and our projections of total harvested land and its regional distribution.[18] Consequently, we consider the amounts and regional distribution of erosion shown in run 2 of Table 6-2 to be more

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[18] As noted in the text, the model generated 17 million fewer acres of harvested land in run 2 than in run 1. This was because in run 2 the model was free to allocate production among regions while run 1 was constrained by our original regional allocation. In the time between the two runs we revised our initial projections of production and yields, resulting in a lower projection of land in main crops, hay, and fallow. Our revised projection of harvested land was almost the same as the corresponding projection in run 2: 417 million acres compared with 423 million acres. We indicated in Section 4 that we modified our initial allocations of regional production and land use to bring them closer to the allocation in run 2. Consequently our final projections of both total harvested land and its regional distribution are closer to those of run 2 than of run 1.

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consistent with our projections of production and harvested land than the run 1 estimates.

Both runs indicate more sheet and rill erosion in 2010 than in 1977 (compare Tables 6-1 and 6-2), both in total and per acre of cropland. Unless wind erosion declines significantly, the projections imply an increase in total erosion. We see no reason to expect a decline in wind erosion, given our projected increases in harvested land in the Northern and Southern Plains and the Mountain States, the regions most affected by wind erosion. Wind erosion is particularly severe in the Southern Plains (see Table 6-1), and our projections for that region show an increase in land in main crops of 15.5 million acres (57 percent) between 1977 and 2010.

These results strongly suggest that if production and yields behave as we have projected them, there will be considerably more erosion from cropland in the United States in 2010 than in 1977, even with a significant expansion of the amount of land in conservation tillage. We concluded earlier that current and future costs of present amounts of erosion are cause for concern. If erosion mounts as our projections indicate, the problem will become more severe, especially if the situation which emerges is like that depicted in run 2.

We have no basis for judging the precise effects of the projected levels of erosion on productivity of the land, but they surely imply that productivity losses would be greater than those resulting from present erosion.

Nor are we able to estimate the off-farm damages of the projected amounts of erosion. We do have estimates, however, of the amounts of sediment delivered to water bodies around the country if erosion increases as our projections indicate. These are shown in Table 6-3, with corresponding estimates of sediment delivered in 1977. The estimates were made by multiplying gross erosion in each year by estimates of sediment delivery ratios.[19] The estimates of sediment delivery ratios are very tenuous, so the estimates in Table 6-3 of sediment delivered should be taken as no more than rough approximations. Even as such, however, they leave little doubt that if erosion increases by 2010 as we have projected, the sediment load in the nation's rivers, streams, lakes, reservoirs, and harbors would increase sharply. Indeed, Table 6-3 indicates it would almost double. The Cornbelt would continue to contribute the greatest amount of sediment, followed by the Southern Plains. The greatest relative increases, all in excess of 100 percent, would be in Appalachia, the Southeast, the Mississippi Delta, the Southern Plains, and the Pacific Coast. (The absolute amount in the latter region would be minor, however). This pattern of regional environmental impacts is much the same as we found with respect to nitrogen fertilizers, and for essentially the same reason. These are the regions with the largest relative projected increases in crop production and harvested land.

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[19] As indicated in the note to Table 6-3, the source of the estimates of sediment delivered and sediment delivery ratios is Gianessi, Peskin, and Poles.

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Should amounts of sediment delivered increase as shown in Table 6-3, the quality of the nation's surface waters surely would be worse than at present. How serious the deterioration would be perceived to be we are unable to say, but we suspect it would be considered of significant national concern, justifying firmer measures to deal with erosion than any previously adopted.

CONCLUSIONS

Our judgment is that the projections to 2010 of crop production and land use do not imply an increasing problem of insecticide pollution. Indeed, it appears that changes in the location of cotton production and innovation in the management of pests of cotton and corn will significantly reduce the quantities of insecticides used. Moreover, the shift toward less persistent insecticides should reduce damages to water quality. Although these materials are more acutely toxic to humans than the persistent insecticides, management of their environmental impacts should be easier. We believe, therefore, that the insecticide problem will be of diminishing importance so far as the environment is concerned.

Given present and foreseeable weed management practices, our projections imply significant growth in the use of herbicides because of the projected increases in both cropland and conservation tillage. Present evidence does not demonstrate that the projected increase in herbicides applied will exact serious environmental damage. There are gaps in the evidence, however, relative to possible damages with present quantities of herbicides, and there may be scale effects that would emerge with the sharply larger quantities projected for the future. For these reasons there is no ground for complacency about prospective environmental damages of herbicides.

Soil and water salinity likely will continue to be a problem in the arid West, even though the amount of irrigated land in the region is not likely to grow much beyond present levels. However, presently known techniques for dealing with salinity, e.g., improved water and agronomic management, breeding more salt-tolerant varieties, appear sufficient to prevent the problem from becoming significantly worse.

If planned measures to reduce municipal discharges of phosphorus are in fact taken, then the projected increases in phosphorous fertilizers should not make the eutrophication problem more serious than it is at present. The projected increases in nitrogen in the Southeast, South, and Southern Plains, however, are relatively large and may contribute to the build-up of water quality problems in those regions.

The most serious threat to water quality by far, however, appears to be from projected amounts of erosion and sediment. While we cannot attach a value to the threat, a doubling of the amount of sediment delivered to the nation's surface waters surely would be cause for concern. When the effects of erosion in reducing the productivity of the land are taken into account, erosion, in our judgment, is easily the major threat to the nation's environment posed by the projected levels of crop production and land use.

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SECTION 7

POLICY CONSIDERATIONS

BACKGROUND

The previous Section showed that expanding agricultural production promises to generate significant new environmental stress, with implications that extend beyond the farm. Policies to cope with that stress will be set in the context of the long record of agricultural policy, but they also must recognize changing circumstances and values outside of agriculture that impinge upon it. A brief review of this changing context is needed.

Agricultural policy and agricultural land policy have been central to the political and social history of our republic. The availability of free or low-cost land was a primary impetus to early settlement and to the extension of the frontier. With land in ample supply, restrictions on its use were not considered. Fee simple ownership and the virtually unrestricted right to use owned property in any way desired were embedded early in the nation's institutions and psyche. Thomas Jefferson's views on a democracy of landowners gave intellectual sanction to this system. Early debates over such matters as tariffs, transportation, banking and credit, policies for the disposition of federal land, and even slavery, all reflected the farmer's eagerness to acquire and work his own land and to sell his products on a wider market. A largely agrarian society of free men in which widespread access to land ownership played a central role was for decades our major dynamic and was a beacon to the world.

The need to adjust to changing competitive, resource, and environmental factors has been present from the beginning. Erosion and soil exhaustion in some of the early settled areas of the South could not be countered by techniques known at the time. Land was abandoned as operations, especially plantations, moved further west. In Appalachia, similar problems often made farming unviable and resulted in populations stranded on unproductive land where they remained for generations. New land to the west had better soils and climate that also made it difficult for New England to compete, especially after improved transportation made the West more accessible. Thus, regional shifts in agricultural production were an early consequence of both economic and technical factors that were reinforced by policies affecting land disposition and transportation.

By the end of World War I (WWI), the center of gravity of American agriculture had moved definitively to the Midwest, and agricultural policy issues had begun to assume their long-term form. Ultimately, two broad

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groups of policy issues predominated: 1) how could farmers be assisted to hold onto their land and realize a decent income in the face of sharp price fluctuations or chronic surpluses of production and the resulting depressed prices? and 2) what assistance could government provide in helping farmers maintain production on lands vulnerable to erosion and drought? Often the two objectives merged, with fragile lands being withdrawn from crops under government support programs to protect both the land and the market. Other land was provided with subsidized water under conservation projects.

Prior to WWI, policy (except for land disposal policy and irrigation projects) tended to operate at a general level through monetary, credit, trade, and transportation measures. Thereafter a shift to the farm level occurred, with policy now operating through government loans, support payments, farm conservation plans, and extension services. The once-independent farmerhas become directly dependent on this policy net and very insistent and influential in the halls of Congress on behalf of public support for the farming sector.

Distress in the countryside, especially among grain farmers, was endemic following WWI. The farming sector entered a period of stress in the 1920s and virtually collapsed in the following decade. What had been an economic problem was now a major sociological issue as land and farmers were compelled to leave farming while faced with poor opportunities elsewhere in the economy. After WWII, the move away from the farm accelerated, propelled now by a dramatic revolution in agricultural technology that increased yields while greatly diminishing labor requirements. Unlike in pre-war years, the swelling cities and growing service economy now could absorb the people displaced, but land and farm commodities still remained in surplus.

During the decade of the 1970s the major human adjustment of the farm economy was substantially completed. The number of low income farmers had been reduced and the size of farm increased to the point where rural poverty no longer was a dominant sociological problem. A series of events--weather, a slower rate of yield increase, and strong foreign demand--evaporated chronic surpluses, raised crop prices, and absorbed idled cropland back into production. Familiarity with soil conservation techniques was now widespread in the countryside, and conservation practices commonly were adopted when profitable to the farmer or if sufficiently subsidized. Despite these changes, the structure of farm programs retained much of the form acquired during the time of surplus; those programs, especially the price support structure, are jealously guarded by farm interests and have become reflected in the value of farm enterprises. All are oriented toward assisting the farmer. When they make him the instrument of conservation policy, they are dependent on his voluntary cooperation. However, with demand for farm products strong again, the once most effective income support and conservation practice--the return of cropland to cover--has lost its appeal.

Yet another important strand of agricultural policy has been the farmer's continuing interest in the widest possible market for his products. Cotton exports once sustained the South, and grain ggshipments built the midcontinent rail system. Exports were quiescent during the protectionist years of the Great Depression, and farm policy focused on domestic policies for averting surpous. With the return of foreign demand after WWII, driven especially in recent years by prosperity in developed countries and by both population and income growth elsewhere, farmers have regained their keen interest in unrestricted exports. Government restrictions on the grain trade are strongly resisted.

The surviving structure of agricultural policy does not seem one that would be suggested de novo for the conditions of today. Farmers have now become substantial businessmen attuned to international markets. They are no more deserving of price supports than are other sectors of the economy that must compete in world markets. Meanwhile, a new environmental consciousness has been born that demands control of environmental insult. It holds economic actors responsible for the off-site consequences of their operations. Farm-related sediment, pesticide residues, and the like no longer are viewed with indifference. At the same time, a new spirit of conservation has arisen that shows concern about limits to the nation's resources; it views preservation of the renewable productive potential of the land as a matter of social interest that need not be left solely in private hands, despite our long tradition of fee simple ownership. Thus, new concerns have been introduced into the policy arena that are less farmer-oriented. It is difficult to know which trends are ephemeral and which will prove enduring. Environmental programs face a somewhat more skeptical reception now than over the past decade. But concern for soil conservation does not appear to abate very much.

Other societies sometimes have neglected soil conservation and environmental matters to their own peril: failure to deal with these issues on a timely basis has been a factor in the demise of some. However, in its long denial of social responsibility for these matters that are of concern to all, our own society has been somewhat of an aberration. In no small part this goes back to our history of unfettered private ownership of land and to the circumstances under which it arose whereby it was both an economically productive and a politically liberating system. Carried to doctrinaire extremes, however, this viewpoint paralyzes the capacity of society to deal with newly recognized and more acute problems of environmental control and conservation.

There is a national interest in the maintenance of an efficient and productive agriculture that permits moderate food prices and generates high export earnings. Sometimes it is difficult to express that interest in ways that are environmentally benign, for that may conflict with the private aims of farmers. While regulation can restrict the way in which land is used by forbidding offending practices, its positive thrust is weaker; it cannot compel private owners to employ land in socially beneficial ways when it is not profitable for them to do so. Therefore, a policy to control the environmental consequences of expanded agricultural production must acknowledge both the legal standing and managerial role of farmers and must not threaten the maintenance of a viable private agriculture. Realistically, policy also must acknowledge the ingrained policy expectations of farmers, for these expectations make abrupt or drastic change politically difficult.

CURRENT ENVIRONMENTAL APPROACHES

Existing programs for soil conservation, water pollution control, and pesticide regulation differ greatly in origin and form and are administered by different agencies. The principal purpose of soil conservation programs is to preserve and enhance the productive potential of the soil. At times, such programs also have become a vehicle for farm income maintenance or for commodity price stabilization, though that is not currently the case. The programs, administered by U.S. Department of Agriculture, are overwhelmingly voluntary. Water pollution control programs are administered by the Environmental Protection Agency but, with respect to agriculturally-related nonpoint source pollution, the agency delegates nearly all planning and control to the states through its program under Section 208 of the Federal Water Pollution Control Act (Clean Water Act). In practice, 208 programs have tended to become extensions of present soil conservation programs. Pesticides are regulated in three ways: through the registration process administered by EPA, through Food and Drug Administration, and through USDA rules on pesticide application procedures. The other major concern of a resource and environmental nature is the preservation of agricultural land. While USDA and EPA have policy positions in favor of land preservation, most initiative in this field lies with the states where it becomes entangled with other nonagricultural land use considerations. Finally, various programs for wetland preservation, upstream flood control, and fish and wildlife habitat have implications for agricultural land use that may be restrictive in character.

Are existing approaches well adapted to meet current needs and the prospective needs suggested by our projections? In order to answer that question each policy area must be examined in order, but it is apparent that the disparate programs do not adequately consider their interrelationships. For example, conservation tillage is a most promising means for reducing erosion, but it implies greater use of pesticides and will be feasible only if they remain available. Their use in turn may aggravate water pollution problems and damage valued nontarget species.

Soil Conservation Programs

Three principal federal soil conservation programs operate at present. The Soil Conservation Service (SCS) Conservation Operations Program provides technical advice and conservation plans to farmers. The Agricultural Conservation Program is a means for channeling money to farmers to encourage them to carry out conservation practices on their land. It is administered by the Agricultural Stabilization and Conservation Service (ASCS) in cooperation with local committees of farmers. The Great Plains Conservation Program is a special effort by SCS to encourage farmers in that area to contract for an agreed operational plan that will reduce wind and other erosion from cropland and range.

The SCS Conservation Operations Program is strictly voluntary. Its purpose is to provide technical assistance to farmers. The initiative lies with the farmer, who must request assistance from SCS. The SCS representative prepares a conservation plan for the farm that incorporates a mix of farming practices or the installation of more permanent features, such as terraces.

A review of this program by the Government Accounting Office (GAO) in 1977 criticized it as passive in not seeking out and concentrating on land with the most severe erosion problems (GAO, 1977). Moreover, the GAO report argued that many of the plans were too elaborate, were not used by farmers, there was little follow-up by SCS, and that the soil loss results for those cooperating with SCS were little different from those who did not. SCS acknowledged the validity of these criticisms. But SCS plays a wider educational role in cooperating with Soil Conservation District members and in other ways, so its impact probably is somewhat greater than the GAO report admitted. The program has enlisted over one-half of all farm units as cooperators. If conservation has not attained its goals, that can hardly be attributed to widespread unawareness of good conservation practice in the countryside.

Soil Conservation Districts (SCDs) or related units play an important role. These units were created under state legislation to promote conservation. Their role is in all cases educational, but in some states they have added powers of taxation and enforcement that permit them to do some planning and to build control structures of wider benefit.

The Agricultural Conservation Program is a cost-sharing program to make funds available to farmers for conservation practices. The program is under the jurisdiction of ASCS and operates through state and local committees that make the actual allocations of funds. SCS provides technical advice to the committees and to farmers carrying out the practices. Again, the program is entirely voluntary. The major objective of the program is to secure enduring soil and water conservation practices that the farmer would not find profitable if financed from his own funds. The ASCS pleads that it has broader responsibility for the protection of woodlands and wildlife as well as water conservation and pollution control, so it should not be held narrowly to the funding of erosion control measures.

In reviewing this program, the GAO found that it was not as strongly focused on soil conservation as would be desirable; over one-half of the available funds went for other measures such as tile drainage, irrigation, land leveling, and liming that were primarily in the farmer's own interests. Moreover, there appears to be a tendency on the part of local committees to foster those conservation practices that are enduring--i.e., structural works--over such nonstructural practices as conservation tillage or rotation systems. The latter could be promoted by term contracts, but this device has not been popular. As a consequence of programs designed by Congress, the ASCS has a split personality. In one program it promotes conservation, which might require the retirement of vulnerable acreage, while in another it offers price supports based on historical acreage--a system that would penalize premature land retirement.

A subsequent ASCS evaluation of the Agricultural Conservation Program supports much of the GAO criticism of this program (USDA, 1980). Their examination of recent experience on agricultural lands (not just cropland)

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found that the acreage on which uncontrolled erosion exceeds 5 tons per acre per year received only 48 percent of all assistance in erosion control practices. Conservation tillage, one of the most cost-effective practices for erosion control, was the practice least often assisted (USDA-ASCS, 1980).

The Great Plains Conservation Program administered by SCS is an effort to induce farmers to change cropping systems and land use to conserve soil and water in that region. The chief practice to accomplish this is the provision of permanent cover on lands especially vulnerable to erosion. The chosen policy instrument is long-term contracts in which the farmer agrees to follow conservation practices in return for government payments. However, when reviewed by the GAO, the program had been implemented on only one-fourth of the intended acreage and had little prospect of reaching beyond half of it by 1981, the terminal year of the program. Strong grain prices induced farmers to return land to cultivation when contracts expired, or to decline those offered. As with other programs, there was little evidence that priority was being given to the most affected acres or to the most effective practices.

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Water Pollution Control

Agriculturally-related water pollution is subject to various provisions of the Clean Water Act administered by EPA. Identifiable point sources, such as large cattle feedlots, are controlled through a permit system that specifies allowable operating practices. Most agricultural pollution does not come from point sources, but rather in runoff from fields. Control of nonpoint pollution is delegated to the states, subject to the approval of state control plans by EPA. Under Section 208 of the Clean Water Act, states are required to plan for area-wide waste treatment management, and the plan is to include "a process to (i) identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution, including return flows from irrigated agriculture, and their accumulative effects, runoff from manure disposal areas, and from land used for livestock and crop production, and (ii) set forth procedures and methods (including land use requirements) to control to the extent feasible such sources." (The Clean Water Act, Section 208(b)(2)(F). The state 208 planning effort thus set in motion has been supported by federal grants administered by EPA. Completion of the plans has been laggard, but the first round is essentially done and most plans have been approved by EPA.

While EPA provided financial assistance and administrative guidelines for the preparation of 208 plans, they have allowed states great latitude in their preparation. In particular, EPA has shunned the assertion of any regulatory role for the agency, even though it has authority for it, and it has encouraged states to favor voluntary approaches as well. The emphasis is on measures known as Best Management Practices (BMPs) that can be adopted by individual farmers on their land to prevent pollution. In most instances the BMPs prove to be familiar soil and water conservation measures to control erosion and runoff, though there also is some emphasis on those measures that inhibit sediment delivery to streams once erosion has occurred. The plans, being relatively new and mostly voluntary, have

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not compiled any real record of implementation to date. However, most contemplate making use of existing administrative delivery systems for conservation programs in the countryside; i.e., they will work thorugh the SCDs and RCDs to contact farmers, and SCS personnel will provide technical help. States may invest their own financial and administrative resources in these programs as well, though few do so on any important scale.

In an effort to give impetus to agriculturally-related nonpoint source control, the Rural Clean Water Program (RCWP) was established by amendment to Section 208 to provide for a program of long-term (three to ten year) cost-sharing contracts for the installation of BMPs to improve water quality. The aim of this provision is to target more directly on water pollution control than is the case with other conservation programs. Responsibility for the program is shared between EPA and the USDA, with the latter having control over field implementation but sharing project approval and the approval of BMPs with EPA.

Funds are available to farmers who are operating under a water quality plan approved by their SCD. Local committees determine priority among farmers for funding. Areas and pollution sources being targeted are those with the most significant effect on water quality, so the geographical scope of this program is restricted to critical areas and sources. As of 1980, thirteen projects were being funded across the country. For a project area to qualify under the program farmer participation must be on the order of 75 percent (USDA-ASCS 1980 Handbook 1 RCWP).

The concept of this program is very promising. It is rather sharply focused on areas with severe quality problems. The projects must be in conformance with 208 plans if they are to gain approval, and many states have looked to RCWP as an important tool for eventual implementation of their plans. Since RCWP provides for cultural as well as structural practices, cost effective measures such as conservation tillage and the maintenance of border strips can be encouraged. The program shuns measures intended to enhance production in favor of those affecting water quality that farmers would not undertake on their own because they are not profitable. The scale of the program is very modest, with initial funding established at $50 million per year. The program is referred to as experimental, and no operating results were available at the time of writing. However, it is clear that funding at this level will not make a major impact on farm-related water pollution nationally.

EPA has provided 208 planning grants and guidelines, reviewed the plans submitted by states, has made some effort to assess the character and severity of the problem nationally, and has approved lists of BMPs to be followed in controlling water pollution. Except for this, most of the responsibility and initiative has fallen to the states to control farm-related nonpoint pollution. Their performance has been extremely variable but most often not deserving of praise. Some states had to start from scratch to establish planning staffs. In many cases they viewed the task as one imposed upon them by federal government and it was not necessarily a response to a problem that they felt deserved attention. Initially, there was concern that the

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federal government would use the law to gain sweeping control over land use in the countryside. That fear has receded, but meanwhile, soil conservation--including its water quality aspects--has assumed a more prominent place on the national agenda, and latent concern about a major federal role may yet be justified.

The authors examined 208 planning in six representative states to learn how it had been conducted: Arkansas, California, Georgia, Iowa, Nebraska, and Texas. They were chosen as representative of major farming areas--not because they are examples of either good or bad water quality or planning. However, Iowa led the nation in sheet and rill erosion and sediment delivered in 1977, and Texas led in both wind erosion and total erosion. Data showing gross sheet and rill erosion and sediment delivered in each state in 1977 and as projected in 2010 are shown in Table 7-1.

In conducting our survey of 208 planning in the six states we interviewed responsible officials and knowledgeable academics in each case, and collected documents wherever available. The survey was done in 1979-80.

Iowa is the preeminent Cornbelt state, with an intensive, productive, and sophisticated agriculture. Corn and soybeans are erosive crops and that, together with the rolling terrain in much of Iowa, and other factors, has caused that state to lead all others in soil lost from cropland. Concern about this problem brought state legislation in 1971 establishing soil conservancy districts and defining maximum allowable soil loss limits on agricultural land comparable to SCS tolerance levels. The law has not been very effective because the state cost sharing envisaged has been minimal. No mandatory action can be taken against violators unless state cost-sharing funds are available to help correct the problem. So far nearly all of the small state appropriation has gone to voluntary participants (EPA, 1979). Moreover doubts have been raised about the wisdom of overly vigorous enforcement of the law because it would place Iowa at a competitive disadvantage vis-a-vis other states (Nagadevara, Heady and Nicol).

The widespread concern about soil conservation has tended to overshadow water quality measures and has presented some real dilemmas. As noted in the last Section, conservation tillage reduces erosion but makes it hard to incorporate some soluble chemicals in the soil, so they appear in runoff. The widespread use of tile drains that carry much nitrogen leached through the top layers of the soil further contaminates water in Iowa. Nonetheless, most attention has gone to erosion and sediment reduction by means of the usual conservation measures (Iowa State U. College of Agriculture, 1978).

While the Governor affirmed that Iowa had a nonpoint water quality problem, very little assessment of its severity was done. The approach was more subjective. The aquatic life potential of the water was taken as a standard and then an attempt was made to identify the pollution sources that prevent attainment of that standard or of the standard of body contact for recreational use.

With regard to 208 implementation, the plan is mostly voluntary in its approach. The intention is to work with those who show a willingness to

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Table 7-1. ESTIMATES OF GROSS SHEET AND RILL EROSION AND SEDIMENT DELIVERY FROM CROPLAND IN THE UNITED STATES AND SELECTED STATES, 1977 - 2010

	1977		2010			
			Run 1		Run 2	
	Gross Erosion[*] (000 tons)	Sediment[†]	Gross Erosion[†] (000 tons)	Sediment[†]	Gross Erosion[†] (000 tons)	Sediment[†]
UNITED STATES	1,925,849	765,113	2,320,210	1,001,110	3,537,031	1,486,418
ARKANSAS	46,711	22,421	36,572	17,555	68,686	32,969
CALIFORNIA	8,591	3,386	6,125	2,389	6,190	2,414
GEORGIA	42,662	14,777	83,445	29,205	92,729	32,455
IOWA	261,253	92,338	104,752	36,663	253,276	88,647
NEBRASKA	117,792	46,871	49,100	19,640	130,854	52,341
TEXAS	99,546	52,539	324,924	172,210	392,971	208,275

Sources: [*] USDA, February 1980, Table 16.

[†] Provided by Leonard Gianessi, RFF. Runs 1 and 2 correspond to those discussed in Section 6. See especially Table 6-3.

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participate rather than to apply pressure on the worst polluters. Any mandatory action is to be left to the conservancy districts. Great hope was placed on RCWP funds at the outset--a hope that now seems largely misplaced.

While Iowans seem acutely aware of water quality problems stemming from agriculture and are disposed to act on them, elsewhere there often has been much less attention to the problem. In neighboring Nebraska, where an expanding irrigated agriculture faces rising energy costs, there was much less attention to water quality and erosion. While a 208 plan was under preparation, the effort encountered great skepticism and frequent questions about the need for it.

Perhaps because of that, unusual emphasis was placed on public participation. This even extended to problem identification. Local advisory committee members were invited to vote on which water quality problems they considered deserving of highest priority. They rated soil erosion as the top priority problem, center pivot irrigation on marginal lands as second, and leaching and runoff of fertilizer and chemicals as fourth and fifth. This hardly impresses as a very scientific procedure, and the planning agency acknowledged the need for further refinement of the list. Discussions with academic experts supported the importance of erosion and leaching, but there was agreement that sediment is not the problem in Nebrasks that it is in Iowa. Many people, including some of those responsible for 208 planning, saw little need for planning, in part because many small rural streams have few beneficial uses in any case. However, contamination of groundwater was acknowledged to be a problem in a state that relies very heavily on underground supplies.

In view of widespread doubts about the need for 208 planning in Nebraska, planners firmly intend to stress voluntary measures for implementation. Those which would be in the farmer's best interests will be promoted. Thus, control of irrigation runoff where nutrients are applied with the water can save the farmer money and should appeal to him. Contour farming and chisel plowing already are accepted in many parts of the state.

Nebraska is the site of one of a half-dozen USDA-EPA model implementation projects (MIPS) where a concentrated attack on rural water quality problems is being attempted on a limited acreage. The problem confronted in this instance is severe erosion from straight row corn cultivation in hilly terrain. Expensive and heavily subsidized terraces are being built on some farms to the neglect of more cost-effect contouring and conservation tillage. Farmers in the area are not strongly motivated to arrest erosion because they have deep soils. Even the water quality benefits seem uncertain, for the small local streams have limited use at best. It is not clear what the project will demonstrate. While such concentrated effort may succeed technically, it is too costly for widespread application.

Texas attempted a very decentralized approach to 208 planning, as befits a state of its size and diversity. The state's Department of Water Resources has primary responsibility for problem identification, which it undertakes by river basin. Although streams in Texas generally carry a heavy sediment load, the state has no standard for sediment and does not

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treat it as a pollutant. Sediment is attributed to natural conditions and is not thought to be closely related to agriculture. In the High Plains area there are no streams, and drainage is to evaporative playas. Sheet and rill erosion is not severe on the rolling plains and is moderate on the black plains; there seems little evidence that it affects productivity significantly in those areas.

Erosion in Texas is mostly by wind, and the amount (14.9 tons per acre of cropland per year - Table 6-1) is well in excess of "T" values set by the SCS. Wind erosion evidently is not viewed as a serious threat to water quality; in any event it does not fall within the purview of 208 planning in Texas, or anywhere else. To the extent that wind erosion in Texas is addressed it is primarily through the SCS's Great Plains Conservation Program. The limitations of that program, as assessed by the GAO, were pointed out above in the section on soil conservation programs.

Water pollution by agricultural chemicals is not regarded as a major problem by 208 planners in Texas. Some leaching of chemicals to groundwater is noted in the winter garden section of the state. In the coastal rice growing areas, a heavy rain just after the application of pesticides may wash enough into bays and estuaries to affect shellfish, though this point is disputed.

The 208 screening process in Texas examined over twenty areas where agriculture was suspected of contributing to failure to meet stream standards, but only three or four involving arsenic, nitrate concentrations, and fecal coliforms were finally attributed to agriculture. The State Soil and Water Conservation Board, an overgroup of conservation districts, has responsibility for developing plans to cope with the identified problem areas. They in turn work with local conservation districts in that process. Land use surveys and the designation of appropriate BMPs are the basis for plans in identified problem areas, and the plans were seen as vehicles for seeking RCWP money for Texas. The conclusion must be that most Texas agricultural land is not affected by 208 planning and the state has minimal enthusiasm for the process. Normal soil and water conservation programs continue, with stress on wind erosion in the High Plains and on contour plowing and water retention in other parts of the state.

Arkansas planners put their main emphasis on developing an information system that should allow them to identify sources of nonpoint pollution. They sought to develop detail on gross erosion and to apply specially tailored sediment delivery ratios for each small watershed. Nutrient and pesticide loads were derived from the recommended application rates for these materials. Identified problem areas are to be more intensively studied. Arkansas has much high quality water in the northwest part of the state, where agricultural pressure on water quality is lower than in the more intensively farmed southeastern delta area.

Problem identification appeared to exhaust the energy of the planners at the time their state was examined. No statewide plan for implementation was contemplated and they foresaw little other than an educational approach with voluntary compliance as likely. It is conceded that streams in rice growing

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areas do not meet standards and are not likely to; little use is made of them for fish or recreation, so there is a tendency to accommodate the convenience of farmers.

Georgia's approach to 208 planning has been extremely cautious. The responsible state planning agency notes that there has been little stream monitoring in agricultural areas, so they cannot document the link between water quality and agricultural activities. Instead they have identified potential problems by assembling data on land use characteristics by county and watershed. From this an erosion potential was computed and a sediment delivery ratio applied so as to rank counties by sediment delivery potential. Sales of pesticides by county were used as an indicator of that problem. The inadequacies of this approach are obvious to planners, and they propose to study in more detail over the next three years the links between potential problems as identified by land use and actual problems seen in water quality. They see sediment as their primary pollutant.

Implementation of the Georgia plan will be left to an overgroup of soil conservation districts who propose to use education and demonstration projects to encourage compliance. While the state has authority to regulate, it does not feel that it has established a basis for doing so or that there would be political support for it. Indeed, throughout the Southeast, while other states have been more specific in identifying problems, nowhere is there support for a regulatory approach. Farmers are not convinced that the problems are clearly enough identified and serious enough to warrant it, and state officials appear to agree. Established state stream standards may be met in Georgia, even though the larger goal of "fishable and swimmable" is not.

California has a long history of water planning, including attention to water quality. The state's agriculture and physical conditions are too diverse to allow a single approach to quality management. Much agriculture is conducted in metropolitan areas where its environmental effects are submerged with those of other nonpoint sources. Intensive irrigated agriculture predominates. While erosion is severe on some hillside orchards and grain fields, much of the land in crops is flat, and erosion is not the major problem in California. Heavy use of agricultural chemicals and concentrated livestock operations in some areas have threatened surface and groundwater supplies, and the state's long history of irrigation has created salinity problems, especially in some fertile areas of the San Joaquin Valley.

Planning under Section 208 in California has consisted of updating already existing basin plans. This is done largely by the state's regional water resources control boards. No single document summarizes their work. The boards have responded to local concerns. Implementation again is left to local conservation districts in the first instance, but the state seems much more willing and able to intervene than in the other states examined. Under the state's Porter Cologne Act they have considerable regulatory authority, many counties have local statutes that can be invoked, and state funds are available to finance water control programs (John Muir Institute, 1979). Moreover, agriculture in California is highly organized, and farm groups are

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willing to bring pressure on identified offenders in hopes of averting more general regulations affecting everyone. As a result, there was a greater sense of ability and willingness to cope with farm-related water pollution. However, state officials and others attribute little of this to 208 planning; rather it is considered to be the product of state efforts that antedate and go beyond 208.

A review of 208 planning on the ground frequently disappoints the expectations generated by federal law. Nonetheless, one should not discount what has been accomplished. States have been forced to face farm generated water problems explicitly and to build planning and administrative capacity to deal with them. This can be an important step if the problems become more aggravated, as our projections suggest they will. The states have had to establish some kind of identification and priority system, however inadequate, and to give evidence of legal authority to act where they deem it necessary. The result has been educational for the states and has led a few to take state initiatives to correct their problems without waiting for federal money. The subtle hint of enforcement that underlies the law has made states, farm organizations, and farmers more self-conscious about the need to act on their own. And the bait of RCWP funds has induced serious planning for some key problem areas that may create its own momentum for action, even though federal money is scarce.

Pesticide Controls

The use of pesticides in agriculture is regulated to prevent the contamination of human foods, to safeguard the health of agricultural workers, and to protect nontarget species (including man) from excessive damage. EPA has primary responsibility for pesticide controls, but other agencies, especially the Food and Drug Administration and USDA, have assigned roles, and states may also regulate to stricter standards if they choose.

Residues of pesticides in food may be directly toxic or they may be suspected as carcinogenic, mutagenic, or teratogenic. Acutely toxic doses would not be expected on food. But because some pesticides are persistent in the environment and are concentrated by biological processes and may accumulate in certain tissues and organs, the possibility of toxicity is present at very low dose rates. Moreover, chronic low level exposure to those chemicals that may be carcinogenic raises all of the murky issues about thresholds and the validity of animal experiments or epidemiological data that so bedevil all discussions of the etiology of cancer.

Responsibility for setting tolerance levels in food lies with EPA. They establish guidelines for the amount of each pesticide that is allowed in different foods. Where processing of raw products reduces the concentration of pesticide, attention goes to the processed product. If there is evidence that pesticides have not been used in accordance with the label, action may be taken against treated food products even if no tolerance levels have been exceeded. Actual enforcement of these regulations is left to the FDA, which monitors food products about the country, and to the USDA, which has responsibility for meat and poultry. Since agricultural commodities

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that do not meet standards are essentially unmarketable, farmers have a most powerful incentive to avoid contamination.

The heart of federal regulation of pesticides lies in the registration and classification process under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as amended. Registration provides information about the contents and effectiveness of the material and specifies the uses for which it can be sold. In addition, EPA may classify pesticides according to whether they are for general or restricted use. In the latter case, they can be restricted to application by certified applicators only. In combination, these provisions are the major protection to man and to other nontarget species from pesticides in the environment. Human occupational exposure is further protected by rules of the Occupational Safety and Health Administration (OSHA). States also play a role in regulating occupational exposure or, in some circumstances, in registration.

The law has proved difficult to administer. The number of compounds on the market is so large (about 35,000) that it has defied attempts at careful evaluation of those already registered (NRC, 1980). As a consequence, EPA's power to suspend or cancel existing registrations has become the focal point of efforts to restrict use. Controversies over individual compounds and classes of pesticide abound, and the scientific basis for decision often is ambiguous. Nonetheless, important agricultural pesticides, starting with DDT, have been cancelled, suspended, or restricted in use.

Chemical companies complain that the cost of developing, testing, and registering or defending a new compound frequently is prohibitive. Since pests tend to develop resistance to insecticides, it is important that successive generations of pesticides become available. Any system of pest control, including IPM methods, will continue to make use of chemicals, even if in smaller amounts. This problem presents a real dilemma for policy. EPA has considerable latitude to interpret the law and increasingly they have used risk/benefit analysis as a judgment tool (NRC, 1980). It is recognized that successful pest management cannot be conducted on a no-risk basis.

Progress has been made in the way in which chemicals are used, not only because of the law but also because of greater environmental awareness. While the standards for the certification of applicators have not been stringent, a more responsible attitude toward pesticide application has spread to farmers and other users. And ever-vigilant citizen environmental groups have channels for complaint against careless users.

Modern agricultural technology has evolved into a dependence on pesticides that is not easily controlled by regulation. Some otherwise benign practices such as conservation tillage increase the need for pesticides. Technologies that would reduce that need can be designed, but generally they require a considerable lead time for development and their development may not offer the same commercial possibilities that broad spectrum chemicals do. Regulation to restrict present chemical use might stimulate alternatives if they were profitable for private firms. Since most alternatives--resistant varieties, attractants, pathogens, cultural practices, etc.--do not offer large-scale commercial opportunities, their development most often depends on publicly supported research. The regulatory program of EPA is not well coordinated with the provision of such alternatives and is weakened by their absence. Clearly, there is need for a longer seeing government strategy in this field.

We conclude that our projections of output and resource use threaten to generate significantly greater environmental stress than current policies have been asked to cope with. The added stress will occur in geographical areas where current programs are weakest and in those areas will show up in the form of erosion losses and attendant water pollution problems. However, tension between the private objective of increased current income and the social interest in maintaining the productive capacity of the soil poses the most difficult problem for policy. It is important to consider alternatives to those policies now in place.

ALTERNATIVE POLICY APPROACHES

The environmental consequences of expanding agricultural production need not be met by environmental policies alone. A whole range of governmental policies do affect or could affect the scale, location, and conduct of agriculture, with implications for its environmental results. Our analysis suggests that the preeminent environmental threat from agricultural activities is not narrowly environmental at all--rather it is the long-run threat to resource degradation from erosion and abuse of the soil. If agriculture cannot be conducted in a manner that holds this loss to acceptable levels, then we are producing beyond sustainable capacity and may wish to consider policies that restrict output. Restraints affecting demand would be one course, although our projections do not indicate any near-term need for this. There also appear to be ways to increase output while controlling soil loss and abuse, but these may involve more intensive use of the best lands and therefore imply other environmental pressures. Such measures would likely change the character and location of production and would affect both individual farmers and producing areas quite differently.

Very likely demand will be left to find its own level and attention will go to better coordination of production, conservation, and environmental policies to support one another. Water quality may be made a more explicit concern of policy, and conservation and environmental policies will be more vigorously pursued with programs focused more sharply on problem areas. Other agricultural programs may be asked to lend support to these objectives. The way in which farming is conducted then may receive more attention than its scale or location, but the result could still be some reduction in output from what it otherwise would be.

Demand and Soil Degradation

In contemporary America agricultural output expands in response to demand--to sales of farm commodities at attractive prices--and expanding output increases environmental pressures of all kinds, but especially the threat of erosion. This demand-driven output differs from that of decades past when individual farmers felt compelled by falling income to produce more but, recognizing the futility of that, collectively were willing to restrict output in return for income support. Conservation measures that idled land or converted it to less intensive use in that context were consistent with the policy of dampening output and removing resources from agriculture in order to improve the economic position of those operators who remained.

Now the pressures are all in the other direction: farmers see their welfare best served by access to growing world markets (where their price must be competitive) and by measures that allow them to expand acreage or intensify the use of presently cropped lands to serve those markets. Past conservation policy was based on compensating farmers for production restraint, but it acted in a depressed market. In current markets, production restraint is both unpopular and costly. Public compensation in return for production curbs could be prohibitively expensive if it is to be effective.

If our soil resource is sufficiently threatened by the accommodation of high demand--if it leads to production beyond long-term sustainable capacity--then measures to restrict demand could be one response. Even though we do not think that severe measures of this sort are justified at present, it is useful to consider what might be done.

The most obvious candidate is exports. The United States exports over one-third of its grain and supplies about 60 percent of world trade in grains. No one can accurately foresee the future, but if the United States maintains its share of world markets, as our projections assume, then most of the large domestic increase in production will go into exports. Restricting exports would reduce output and greatly ease the pressure on U.S. agricultural land.

To do so would of course be very unpopular with domestic producers and counter to the U.S. policy of promoting freer trade. It also would antagonize buyers whose amity we cherish. In a world short of food, it might be considered an inhumane policy. It also would be argued that we need the exchange generated by farm exports to finance petroleum imports. In response, it could be argued that the degradation of a renewable resource--land--in order to satisfy a bloated and ephemeral demand for oil is a bad trade and that energy conservation or domestic fuel alternatives should be sought instead. Restrictions on exports could be managed so as to accommodate favored friends and customers, though not without damage to the world's trading system. Humanitarian responsibilities are not unlimited, and, in a world of national sovereignties, every nation must look after the health of its own renewable resources, since no one else can. Yet restrictions on trade surely do not deserve early attention as a conservation policy. Many other policies to control erosion that are consistent with high output should be explored first. If the problem becomes acute enough to warrant restrictions on trade, they could be instituted quickly.

Nonetheless, it seems likely that American agricultural products are sold too cheaply on world markets and, therefore, in greater quantity than might otherwise be the case. Both the subsidies that abound throughout U.S. agriculture and the environmental costs of production are not being reflected in price; therefore, the United States subsidizes foreign buyers, including both developed countries and East Bloc adversaries. The increased domestic environmental damage and soil degradation that result are real costs paid by current and future generations of Americans. In principle, there can be no objection to policies that correct for this underpricing or subsidy to consumers of agricultural products, especially of those foreign buyers who bear none of the domestic fiscal or environmental costs. The preferred solution would be to root out the subsidies at the source or to reflect all external costs in the price of agricultural commodities. However, that would be a major undertaking--the present structure of agricultural policies is simply too deeply embedded in our system. An export levy might be a more feasible way of attacking the foreign component of the problem, but it carries the disadvantage of penalizing those producers who may not use subsidies or create environmental problems. Politically, and perhaps constitutionally as well, it also would be difficult to accomplish.

Export demand also may be limited by fostering production abroad. To the extent that demand is from developing countries and our concern is humanitarian, there should be no objection to policies that assist them and spare our own soil resources. This would involve transferring and developing technology suitable for their conditions and assisting in the development of new land and water abroad. By creating the capacity for others to help themselves we respond to the themes of self-reliance and independence now so strongly asserted in the developing world.

Domestic demand is not a dynamic force for agricultural expansion, but its composition could be altered so as to reduce pressure to produce by shifting the diet away from grainfed meat animals. To do so need not result in any loss of nutritional adequacy and might even produce health benefits. There is growing evidence that meat eating on our present scale is not necessary for a healthy diet and may even be harmful to it. The confirmation and publicizing of this evidence could significantly alter our diet and demand for grain. Recent price increases for feed grains, as they become reflected in the price of meat, also serve to curb the domestic appetite for meat.

Finally, it should be possible to spare cropland by making better use of forage resources and unconventional feeds. Improved management of public rangelands is one obvious possibility. At the same time, much agricultural and forest biomass not previously used by animals is proving adaptable as feed.

Soil Loss and Social Responsibility

Most farmland is private property. So long as the farmer does not use it in a manner that harms others, should he be free to use his property as he chooses, even including the destruction of its productive potential? Note that we do not ask that question about many kinds of property. A manufacturer can allow his plant to go to ruin if it suits his operating strategy, and a skilled professional trained at public expense may allow that investment to go unused. On what grounds, then, can the public intervene when farmers find it advantageous to treat their land assets as depletable?

The narrowest argument is one of market failure--that there may be differences between private and social time horizons and between private and social discount rates. Studies have shown that farmers have little economic incentive to control erosion and that they would need very long time horizons and low discount rates for such control to be economically rational. For example, a study by Seitz, et al. shows that conservation practices in a Cornbelt study area would not be rational, even at zero discount rates, unless the farmer's time horizon was forty years or longer. Even a modest 5 percent discount rate extends this period to sixty years (Seitz, et al., February 1979). Given realistic private discount rates, the farmer is not likely to act, and over a 100-year period the above authors found that over half of the area studied would lose all topsoil. Thus, purely private motivations may not surface to protect society's interest in soil conservation.

Society may choose to operate with an infinite time horizon (we do hope to endure as a society) and, lacking visible substitutes for soil, may determine to manage the land as a perpetual rather than a depletable resource. The logic for doing so is that (unlike with depletable energy or mineral resources) the option exists and that future generations should be given access to this resource equal to our own. Note that this becomes an ethical rather than an economic choice. Thus, no discounting is appropriate to such a decision.

Others might reject a noneconomic rationale but still concede that the enormous uncertainties concerning future demand for land and the irreversible character of soil loss (within an economic time horizon) argue for a very low social discount rate that would justify conservation measures. Of course uncertainty applies to all aspects of the problem, and it is conceivable that future technical progress may diminish the importance of the soil resource. Sufficient confidence that "something may turn up" would be a basis for treating soil like any other input to be used according to current market dictates. Nonetheless, there is a broad public commitment to the idea of soil conservation, and few would be comfortable with a pure market solution that treats soil as a minable resource (Harris, 1980).

A society with an infinite time horizon has an interest in restraining the loss of the soil's productive capacity, for that loss imposes a cost on future generations. But is there any basis for making the cost of prevention a responsibility of current private holders when they impose no current off-site costs on others? The legal foundation for restricting the use of property is the need to protect public health and safety, but it stretches the police power severely if it is asked to regulate matters that are so remote in time and that affect no identifiable current victims. To the extent that such problems are dealt with at all, it is through an implicit intergenerational bargain involving the whole society rather than individual actors. For example, the current consumption of exhaustible resources that may deprive a future generation of their use is not something for which each present individual is held directly accountable. Rather we view broadly borne restraint and social investment in resource-replacing technology as the way to meet our obligation to the future. Likewise, if we wish to protect the rights of a future generation in a productive soil, the

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equitable way of meeting the current costs of doing so would be to make them broadly borne.

The farmer has both operational control and constitutionally protected property rights on his land. So long as damage is confined to his own acres, it is not clear that he can legally be compelled to correct it. Further, it might appear inequitable for society to require that its interest in preserving the soil be accomplished at his particular expense rather than being broadly borne. From an equity standpoint, it appears that the farmer should be compensated for his expenses in income forgone in return for achieving some socially desired level of soil conservation that lies beyond his own best interest. This principle is even more important because of the farmer's operational control over the land and the fact that he must be the instrument for effecting whatever measures are taken.

Soil Conservation Policies

The accomplishments of the present system should not be denigrated. Farmers are well informed on what can be done to limit soil loss. They appear to have a decent appreciation of what conservation steps are in their own best interests and have gone far toward applying them. Allegiance to a conservation ethic is widespread; under its influence many farmers undoubtedly undertake conservation measures not justified by private economic calculations. In effect, they pay a self-assessed tax toward a public goal. Other farmers have accepted contracts and installed conservation practices on a cost-shared basis, thereby helping to restrain soil loss. In this case they may also have enhanced the value of their own property at public expense--an outcome that can result from any public subsidy to private action.

Under a low or moderate demand scenario, current policies might suffice to achieve a socially acceptable level of soil loss, especially if they were targeted better on key areas. However, the demand scenario we have projected carries the risk of soil losses far higher than at present. The public is not likely to accept the 84 percent increase in soil lost from cropland or average per acre losses of over 7 tons per year from the expanded area in crops that appears in our run 2 (see Table 6-2).

Whether or not the pressure becomes this acute, existing programs can be better focused. The GAO study comments are especially applicable here (GAO, 1977). Detailed farm conservation plans are not needed in many circumstances, yet SCS spends an inordinate amount of time on them to the neglect of more critical problems. The passive approach of SCS means that scarce manpower resources go to those requesting help rather than to those who need it. Meanwhile, because ASCS allotment programs are based on historical acreage, they encourage farmers to plant crops on land that should be in other use. The GAO report recommended that SCS systematically seek out farmers with the most critical erosion problems, tailor its conservation plans to their major problems without being overly elaborate in the plans prepared, and coordinate with other agencies to relieve program conflicts. Likewise, the GAO criticized the lack of priorities in assigning ACP money by area and form.

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Not all of the GAO criticism seems well directed, however. While the government should not be paying for measures that the farmer would find profitable to increase his productive capacity, from a social standpoint, why does increasing capacity differ from preserving capacity for which we so readily accept a government role? Perhaps the criterion for government support in either case ought to be whether it is profitable to the farmer. If not, then we should aim at supporting those lands and measures that offer the highest favorable social benefit/cost ratio for public investments at whatever discount rate, if any, is selected. In particular, short-term measures that are highly cost effective in controlling erosion should not be dismissed in favor of longer-term structural measures that are less so.

The present system has had only moderate success in dealing with existing pressures on the land. It contains a social element in appealing for the practice of good husbandry, but mostly it has relied on the farmer's acting in his own interest and has provided him with information and technical support to do so. In addition, it has included subsidy elements in the form of cost sharing for installing practices that are not justified by the farmer's private interest. Fine tuning of this system would be a help, but when commodity prices make it attractive to abandon conservation measures, it is difficult to resist the pressure. The experience with the Great Plains program cited earlier is the best evidence of this, and elsewhere the widespread return to crops of acreage once idled by conservation programs is additional evidence. If a high export scenario prevails, more compelling inducements to maintain conservation practices will be required.

The draft RCA study establishes targets (essentially the achievement and maintenance of "T" values) and lists alternative strategies for achieving them (USDA, RCA II, 1980). Since the export projections used in that study are lower than ours, their policy recommendations are directed at a less acute problem. Thus, while their alternatives of organizational reform and reassigning responsibilities to make current programs more effective could help, the crunch comes in the choice of devices to induce compliance.

Inducements may be either positive or negative--i.e., desired behavior may be rewarded or undesired behavior penalized. One proposal that has received much attention is the idea of cross compliance (Benbrook, Journal of Soil and Water Conservation, 1979). In negative form this would penalize farmers who fail to employ good conservation practice by withdrawing from them the benefits of other federal programs, such as price supports. In positive form it would offer favored treatment in benefits from these programs to farmers using good practices. Farmers prefer the second approach and have been highly critical of the penalty version. While that preference is understandable, it is hard to see why farmers should be granted a vested right to public benefits when they ignore public policy.

Yet the idea of cross compliance has several other drawbacks. Not all farmers use the benefit programs, so the reach of this device is incomplete. It is also unselective and would not focus on those lands most in need of attention. Moreover, in a high output scenario, federal price support programs would become of less interest to farmers at the very time when erosion control becomes a more acute problem. Finally, from the standpoint of social strategy, it may be unwise to tie a long-term concern with soil erosion to an array of agricultural policies that may not deserve continued support on their own merits. To do so would tend to embed those policies further into the system at the very time when they otherwise might be modified.

Taxation can be used either as a reward or penalty. Property taxes could be lowered for those following good practices, for example. This would require state/federal cooperative arrangements to encourage states to participate. But manipulation of general purpose taxes for special purposes, while widespread, should not be encouraged. A punitive tax on socially undesired behavior could be quite effective in theory and would have certain efficiency benefits. Thus, a soil loss tax would provide powerful incentives for the farmer to employ conservation measures while allowing him full latitude to do so in the next most efficient way (Seitz et al., 1979). It is objected that such a tax would be difficult to administer, though it is hard to see why it should be more so than a cross compliance scheme. The tax could be made operative only when losses exceed the "T" level. Note that a soil loss tax, if unrelated to sediment delivery beyond the farm, places the burden on the farmer to achieve the social objectives of preserving his land's productive capacity. Therefore, while the tax may be employed as an incentive, it could logically be combined with subsidy programs that relieve the burden on those willing to cooperate.

Present subsidies for conservation practices are in the form of cost sharing programs. Being voluntary, they do not attract all farmers and perhaps not those with the worst problems. Since the farmer still must pay some part of the cost, he has little incentive to act unless the measure increases his capacity in proportion to his own investment. Further, he is tempted to install those practices for which money is available, even though these may not be the most efficient ones in his case. As a consequence, the public gets poor value for its money.

A system of contracts between farmers and government to reduce soil loss has much appeal. It would allow the program to target on those areas and on the specific acres that most deserve attention. The contract could be written to specify performance, allowing the operator to arrive at the most efficient means of achieving it. Good cultivation would not be at a disadvantage in this sytem; thus the public not only would get what it pays for but would not pay more than necessary. As the RCA study points out, the contracts could be flexible, with provisions for the owner to "buy out" if market conditions change, and he could trade off other conservation measures for those he wishes to abandon if the government agrees (USDA, RCA II, 1980). A possible weakness is that the farmer might be able to exact payments on land that he would not crop for his own reasons, but that defect has been present in past conservation programs. Administrative costs are expected to be high.

The Great Plains Conservation Program operates on a contract basis but, as was noted by the GAO, it has not enlisted the desired participation rates or been able to restrain the reversion of grassland to crops at the end of contract periods. Evidently contract prices must be realistic in meeting the cost to the farmer of doing society's work for it, yet they should not

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exceed the value of the social benefit derived. If the farmer is fully compensated for all costs, including opportunity costs, there is no reason for him to resist the contract, and the same applies to renewal if the contract reflects the changed conditions prevailing at that time.

Nonetheless, the program need not be entirely voluntary. Where reasonable contracts are offered, the operator's defense for declining to take conservation measures vanishes. If he still resists, he could fairly be coerced, either by tax or by regulatory measures. A soil loss tax paid by those who decline to contract would encourage participation. It seems preferable to regulation, for it gives the operator yet one more chance to do the job in his own way while still protecting the public interest.

The threat of regulation to encourage farmers to contract is consistent with protection of the public interest. Major reliance on regulation alone is apt to disappoint, however, for it is very difficult to compel a farmer to undertake specific measures on his own land. Moreover, if the purpose is primarily conservation beyond that which is profitable to the farmer, then the equity of imposing the costs on him is questionable when damage is confined to his own land. Thus, regulation appears better suited as a backstop to a system of contracts, but it would appear inferior in that role to a soil loss tax.

Any subsidy scheme to induce good soil conservation is premised on acknowledgment of the sanctity of an owner's property rights. In effect, it concedes his right to use his property in a socially undesirable way unless he is offered compensation to refrain. This is a familiar but not unchallenged position. Where property is not involved, we do not allow unconstrained pursuit of private purposes without regard to social welfare. It is troublesome to contemplate a society where antisocial behavior is restrained by a complex system of compensating payments in perpetuity. But a purely voluntary ethic does not work or works very unevenly. The legal right of an individual to dissipate his capital (soil) in favor of current returns may come into basic conflict with society's preference (or obligation?) to maintain the resource base intact. This entire dilemma could be avoided by acquisition of certain property rights, but if we want to "take" some aspect of property rights, then it should be done cleanly, openly, and once for all.

A contract system does not by itself ensure that an optimum amount of erosion control is purchased by public funds. In some cases the cost of soil conservation may be so high that even from a social accounting standpoint it is rational to mine the soil rather than preserve it. Before conceding that to the operator, he should be made to face the off-site consequences of such action.

Water Pollution Control Policies

The preceding section has dealt with policy to control soil loss so as to maintain productive capacity. Such policy confronts a landowner who can argue that his property is his to manage as he sees fit so long as he does not currently harm others; a legitimate public interest here must accommodate equally legitimate property rights. But if the owner's actions do harm others, then it is usually accepted that he is accountable and may be restrained by appropriate measures. Farm-related water pollution fits the latter case. Since much farm-related water pollution is entrained with sediment, the two problems of erosion and water quality often are treated as one, though the distinction can be important in designing program emphasis or in assigning cost incidence.

Throughout the private sector, measures for environmental amelioration have been made the responsibility of the offending party. Auto manufacturers must design cars to meet standards at their own expense, utilities pay to control emissions at standard levels, and best available control technology is required of manufacturers discharging to streams. The final incidence of these costs depends on market structure, but the costs do generally become reflected in prices paid for the products and, therefore, affect production and consumption decisions.

Nonpoint sources other than agriculture are subject to a variety of controls, but the agricultural sector generally has been accorded more lenient treatment. It is hard to understand on what principle this should be so. Sometimes it is argued that the costs of such measures are difficult to pass on to consumers because markets are competitive and therefore costs come to rest on producers. What kind of an argument is this? It only serves to perpetuate the problem. If costs were promptly reflected in decisions on how much, what, and how to produce and ultimately in commodity prices, this would help to reduce farm-related pollution.

Administratively and politically, however, it is very difficult to impose both the cost and the responsibility for control on the farming sector. The number of units to be controlled is large, data on effluents from a given farm are lacking, and the consequences of their discharge hard to establish. Moreover, EPA has no bureaucracy in the countryside and would not be welcomed there, and USDA, which does have what they call "delivery systems" is loath to be perceived as regulator rather than servant of their clientele. Existing programs for farm-related water pollution control are mostly based on education and voluntary measures, with the latter sometimes induced by cost sharing. Indeed, the cooperative and voluntary tradition employed by institutions in touch with farmers is so much a part of farmers' expectations that abrupt change seems quite infeasible. Selective regulation can be admitted--in some states where problems are acute local authorities can act through regulation--but the enforcement of generally applicable rules is much harder to envisage.

The RCWP projects now getting under way represent a concentrated attack on some of the more acutely affected areas, albeit with the usual congressional sensitivity to regional distribution. Since one can have reservations about the equity and the economic consequences of public subsidy to the abatement of privately generated pollution, it might be argued that this program should be kept small. In any case, a limited budget should help to focus the program on the most troubled areas where the returns from public investment should be high. Given the rather poor documentation of farm water

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problems and the damages they cause, this seems to be a politically realistic approach.

Even within this basic framework, state and local authorities, and Soil Conservation Districts could be more aggressive in disciplining blatant offenders. Direct counselling and local enforcement seem to have had some effect in California, and there is no need to await ponderous federal legal processes before attempting these simpler approaches.

Another possibility within the existing framework is to make farm conservation plans more explicitly water quality plans as well. The plans already are criticized as overly elaborate, but most of them were prepared with an eye to soil conservation rather than water quality, and they may have neglected simple and effective measures conducive to quality. As new plans are prepared or old ones modified, this defect should be repaired. Experience with RCWP and with some experimental model implementation projects (MIP) should give SCS an opportunity to sharpen its approach to water quality control.

If our projected scenario prevails, however, then water quality problems attributable to agriculture likely will be much more severe than at present. They will be mostly sediment-related and will increase in all regions, but particularly in the nation's agricultural heartland--the Cornbelt, Southern and Northern Plains, Mississippi Delta, Appalachia and the Southeast (see Table 6.3). There will be wide variations among regions, however. Measured by the increase in amount of sediment delivered, the Southern Plains will be by far the most seriously affected. This is a region now little concerned about or prepared to cope with increased pressure. Among the major producing regions the Cornbelt will be least affected. The Northeast, Mountain, and Pacific regions will all experience substantial percentage increases in sediment delivered, but the absolute amounts will remain relatively small. These disparate trends, while stressing the need for programs that are responsive to local conditions, also suggest that it may be necessary to stiffen local resolve in some cases.

See Table 6.3).

Whenever federal programs differentially affect some areas there is a cry of unfairness and a call for equalizing payments. If there is unfairness, it is in the needless application of uniform national point source regulations that cause differential effects. However, water quality is a local responsibility. Except for the broad goal of fishable and swimmable waters, nonpoint pollution control will be pursued in relation to state established stream standards. There are no effluent standards for nonpoint sources. Differential regional impacts could occur through simple nonenforcement or through competitive degradation of streams standards in order to retain local production. If stream standards are set in some objective way and are enforced, then any depressing effect that water quality control may have on local farming activities is a reflection of the comparative advantage of local land resources and need not be equalized by national payments. Some areas may be disadvantaged, and local farmers may lose income and capital values, just as any segment of society may do by change, but they are not unlawfully or unreasonably deprived according to any standard of equity.

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It is clear that under our projected scenario EPA may need to take a sterner view of 208 plans and, especially, of their implementation in some districts. States could be encouraged to identify quality problems more precisely and to coordinate with federal programs so that water quality measures could more effectively go piggy-back on conservation measures where conservation receives high priority, or so that quality can receive direct attention if conservation does not.

The affected states will have the responsibility to implement stronger measures for farm water quality control. They cannot expect equalizing federal grants to protect their agriculture from adjustment to the need to protect quality. However, federal money is likely to be available for measures primarily aimed at conservation, and fairly inexpensive adaptations to such measures could have important quality implications. Thus, states that are threatened by severe quality problems would be advised to strongly support conservation programs for which federal money is available and to backstop such programs with provisions for penalizing those farmers who fail to cooperate. If the contract/soil loss tax combination is available, it should provide a state with such an opportunity. However, the water quality dimensions of conservation plans must be developed in cooperation with the federal technical services.

It is worrisome to note the asymmetrical character of conservation programs, which we have argued should be federally supported to the extent that they protect a social rather than a private interest, and water quality programs, that, being an external cost, should be the farmer's responsibility and become reflected in price and production decisions. The implications of these two positions for the location and profitability of production are quite different. Were there no vested rights to consider, conservation could be required up to a socially established level just like quality control, with the operator absorbing any loss of income and capital that might imply, but in our view equity argues against that. Our position on responsibility for environmental protection is consistent with practice elsewhere in the society, however. If we choose inconsistency with other environmental rules and are willing to ignore the budgetary consequences, we can subsidize quality control just as we do conservation.

In practice the two principles can support one another. A soil conservation program makes sense from a social standpoint on much private land. It may require the retirement of some land from crops and the less profitable use of other land. The farmer must be given inducement to do that which is socially rational. A realistic subsidy is at the center of this. But his sense of responsibility can be accentuated by making him responsible for the off-site consequences of soil loss. The conservation objective pursued by performance contract or like device can be backstopped by a soil loss or a sediment tax grounded in quality control for those unwilling to accept the conservation objective freely. Soil miners at least would be deterred to the extent of paying for off-site damages. And in all cases the incentive to use the most efficient methods for obtaining target objectives would be preserved. Moreover, both subsidy and tax could be, and should be, varied by area to reflect the real social value of the objective sought.

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Research as Policy

Increased environmental stress from agriculture originates both in the expanded scale of production and in the technologies employed. New technologies often are seen as posing added threats, but if they are pursued with the need in mind to accommodate production while diminishing environmental impacts, then the outcome can be quite different. Moreover, if we are to avoid both surprises and needless fears, there is a need for better information on the consequences of changes in technology and scale of production. Thus, research on which to base both control actions and environmentally benign new technologies can be an important policy tool. The principal policy issues are those of the scale and the focus of the research.

Concern about research has been implciit in much of the previous discussion in this volume. We noted that knowledge of where to focus programs for environmental amelioration is skimpy. State 208 plans, intended above all to identify nonpoint sources of water pollution, have not increased the precision of this information as much as was hoped. In general, excessive reliance is placed on estimates derived from application of the Universal Soil Loss Equation and on large models with obscure and coarse assumptions rather than on selective direct measurement. EPA could help by identifying and publicizing the more successful problem identification approaches found in state plans.

There is always a temptation for a single mission regulator to attack those problems that he perceives directly without full attention to the possibly adverse displacements that this may cause elsewhere for other objectives or, indeed, even for the one intended. Although EPA has the principal environmental regulatory authority, they do not have the detailed knowledge of agriculture that would permit them to assess these tradeoffs and they have little incentive to research them thoroughly or to seek technologies that may restructure them. One course might be for EPA to give firmer long-range guidance on ambient needs and then allow the states and/or USDA to structure controls and related research programs to meet those needs.

However it is triggered, detailed research is needed on the most effective ways of meeting ambient goals. Several possible directions for research come to mind. Alternative pest management strategy is an obvious candidate. The need is both to develop new chemicals and to perfect management techniques that rely less on chemicals. Conservation tillage implies greater use of herbicides and perhaps insecticides. The chemicals may move and degrade differently under sustained use in this system--a matter that should be better understood. The use of fertilizer also needs study. While the leaching of nitrogen presently is a spotty problem, our projections suggest it may become more severe and more general.

Environmental concerns need to be a more active component of agricultural research aiming at yield increasing or cost reducing technologies, for if the latter are not environmentally tolerable, they will fail. Increasing yields, especially on the best and least vulnerable lands, can relieve pressure on the environment. The rapid strides in the biological sciences of recent years so far have not been translated into new varieties on any great scale; there is an uncertain but possibly large potential to do so. Targets might include plants that are more efficient synthesizers, more pest or drought resistant varieties, and varieties with greater protein content. Conventional plant breeding and cultivation research might give attention to soybeans--an important crop whose yield is not impressive. Advances in these areas should permit higher yields without greater environmental hazard. A related possibility is the development of more unconventional feeds for animals using resources presently unutilized. Even the development of new markets can be an important innovation if they allow more intensive (viz. corn/soybean combinations) use of good lands or the substitution of higher yielding crops (e.g., sunflowers for wheat).

It would be helpful for agencies to be more aware of the productivity and research implications of regulatory actions. Regulation that restricts the use of current technology (e.g., pesticide use) may divert scarce research resources into compensating for the lost techniques. And regulation may discourage private spending on research (e.g., in pesticides or genetic engineering) if it is not sensitively designed.

Agricultural research is especially susceptible to policy because so much of it is the province of government. Agricultural commodities are undifferentiated and are sold by small firms that are unable to undertake costly scientific research of the kind needed. Research by private vendors of supplies and services can be an important contribution in some areas, but the government has an uncommon opportunity in this field to set the priorities and the scale of the program in response to an integrated appraisal of social needs.

A Final Word

American agriculture has always been one of our nation's greatest strengths. From the first Thanksgiving to the factory farm, it has responded to the needs placed upon it by our society. The challenge posed in this study is whether agriculture can meet the high level export demands that it may face in the future without irreparable damage to the productive base or unacceptable cost to environmental quality. On the whole, we conclude that it probably can, but that social controls are likely to intrude more into the countryside than in the past if major objectives are to be met. If we wish to avoid land use controls, then pressure on the land can only be relieved by reducing demand or finding land substitutes. If we want to pursue all objectives simultaneously, then conservation and rural water quality programs must be operated more efficiently and in a mutually supportive manner.

Any set of distant projections, such as those attempted here, is subject to wide error. If the demand projections are too exuberant, much of the potential problem vanishes. Others have been more conservative than we in projecting demand, but we think that our scenario has sufficient plausibility to deserve attention. The implications of such a level of production for the use of land and other resources is also subject to interpretation. Per acre yields must rise if demand is to be satisfied within the land resources that

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we are likely to be able to devote to crops. We think that condition can be met, but we do not expect the past yield trend to be matched. Fertilizer use will grow, but if better use is made of that applied, it will not outpace production growth. Future pesticide use will depend on the location of production and on the techniques of pest management and cultivation employed, but declining use of insecticides on cotton and moderation of use on corn suggest that no explosion will occur in this area.

The primary consequence of expanded production that has held our attention is damage to the soil resource from erosion and the consequent damage to water quality as this is discharged as sediment to streams. Preserving the productive capacity of the land seems to deserve the highest priority. But damage to the soil is a function not only of the scale of production but also of the cultivation practices and the location of production as well. The spread of conservation practices, especially conservation tillage, gives promise that any given output can be produced with less damage to the soil. However, not all soils or crops are suited to this practice, and we have been more conservative in projecting its adoption than some other projections have been. As a consequence of this (together with our demand projections), we foresee potentially grave problems from agriculture. They will not be moderated much by geographical production shifts, for any such moves will be toward vulnerable areas of the country. Explicit and vigorous soil conservation tillage implies increased pesticide use, especially herbicides, with consequences that cannot be entirely foreseen; therefore other pest control techniques must continuously be explored.

Our cautious optimism is meant to reflect confidence in the physical capacity to meet demands and our belief that the environmental consequences are on a scale that is manageable in principle. However, the latter will not occur automatically. There must be recognition that a more heavily stressed agricultural system may demand closer control if it is to continue to expand without damage to productive capacity and environmental quality. Much better monitoring and data on farm-related pollution should be sought so that adverse trends can be spotted early and policy designed to meet them. With these significant caveats, we believe that American agriculture will continue to meet its domestic and international challenges.

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APPENDIX A: DERIVATION OF PROJECTIONS OF PRODUCTION

PROJECTIONS OF WORLD TRADE

WHEAT AND COARSE GRAINS[1]

The projections of world trade in these commodities are based on analysis of trends in production and consumption in importing countries and groups of countries, namely the importing developing countries, Western Europe, Eastern Europe, the Soviet Union, the People's Republic of China (PRC) and Japan.

Importing Developing Countries[2]

Much of the relative increase in demand for food in the less developed countries (LDCs) has come from relatively few among them with higher than average income and income elasticities of demand. This is an argument for considering these countries apart from the other LDCs. We decided that for our purposes the improvement in our projections from doing this would not justify the extra effort required.

Projections of food consumption typically are based on projections of population, per capita income, and income elasticities of demand. The World Bank (1980, pages 142-143) projects population growth in the importing developing countries as defined here at 2.2 percent from 1980 to 2000. Although the Bank report does not indicate this, rates of population growth in these countries are declining, and one recent projection is that by 1995-2000 growth in the developing countries will be 1.62 to 2.00 percent annually.[3] Accordingly, we assume that in the countries of interest to us population growth between 2000 and 2010 will average 1.7 percent per year. In this case average annual growth over the full period 1980 to 2010 would be 2.0 percent.

The World Bank (1980, page 99) shows that in the 1970s real per capita GNP in the developing countries increased 2.8 percent annually, down from 3.1 percent in the 1960s. The Bank expects per capita GNP in these countries to grow only 2.6 percent from 1980 to 1985 because of the steep increase in oil prices in 1979. Between 1985 and 1990, however, the Bank expects GNP per

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[1] World trade data are for coarse grains rather than feedgrains as defined in Table 1-1. Coarse grains as defined by the USDA are feedgrains plus millet and "mixed grains."

[2] For wheat these are all countries of Asia, Africa and Latin America except the PRC, Japan, South Africa and Argentina. For feedgrains these countries as well as Brazil and Thailand are excluded.

[3] Projections by the Community and Family Study Center, World Bank, United Nations, and U.S. Bureau of the Census, reported in Tsui and Bogue.

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capita in these countries to grow 3.3 percent annually, reflecting a successful transition to a world of permanently higher, and continually increasing, prices of oil. We assume that growth at 3.3 percent annually will continue to 2010. In this case real per capita GNP over the entire period 1980-2010 will average 3.2 percent per year.[4]

The income elasticity of demand for grains in the developing countries is between .3 and .5, being higher for wheat and lower for coarse grains for direct consumption (USDA, 1974, page 77). However, in countries with incomes sufficient to support rising demand for meat, the income elasticity of demand for coarse grains for livestock is relatively high. If real per capita income in the developing countries increases by 3.2 percent annually, the demand for animal products is likely also to grow steadily, maintaining steady growth in demand for coarse grains.

In summary, if population in the developing countries grows 2.0 percent annually from the late 1970s to 2010 and per capita income grows 3.2 percent, then demand for grains in those countries could reasonably be expected to grow 3.0-3.5 percent per year over the period as a whole.

Table A-1 shows production and consumption of wheat and coarse grains in the importing developing countries in two periods since the mid-1960s. The periods were selected to reflect the impact of the Green Revolution in these countries on production and of the increase in oil prices on both consumption

TABLE A-1 AVERAGE ANNUAL GROWTH RATES IN IMPORTING DEVELOPING COUNTRIES, WHEAT AND COARSE GRAINS*

	1966-1979	1972-1979
	(percentages)	
Wheat		
Production	4.9	3.4
Consumption	4.8	3.9
Coarse Grains		
Production	1.0	3.4
Consumption	3.1†	4.3

*Calculated from the logarithmic time trends. Sources are various issues of USDA, Foreign Agriculture Circular Grains. Data are world totals of production and consumption less Western Europe, Eastern Europe, USSR, PRC, Japan, U.S., Canada, Australia, South Africa, and Argentina (for wheat); the above countries plus Brazil and Thailand (for coarse grains). Coarse grains are corn and sorghum for grain, barley, oats, rye, millet and mixed grains.

†1968-1979

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[4] Schnittker Associates and the Food and Agriculture Organization project per capita income growth in the developing countries at 3.2 percent annually from the mid-1970s to 2000.

and production. With respect to wheat the most notable feature of Table A-1 is the slowdown after 1972 in growth of both production and consumption. The slower growth of production likely reflects the relatively slower growth of the Green Revolution after the initial burst in the mid-1960s. The heavy dependence of the Green Revolution technology on irrigation and the difficulty in rapidly expanding the irrigated area in these countries probably is a major reason for the slower spread of the Green Revolution since the early 1970s. Higher prices, and occasional disruptions in supply, of nitrogen fertilizer in this period may also have contributed.

The slower growth in wheat consumption after 1972 likely reflects the slowdown in growth of production. While there is no necessary connection between the growth of consumption and production of wheat in these countries, balance of payments constraints imposed by sharply higher oil prices after 1973 likely would have prevented wheat consumption from growing at the pre-1972 rate, given the slowdown in production growth. In addition, real wheat prices may have been higher after 1972, although we have not pursued this possibility because of the complexity of internal pricing policies in these countries.

We believe that the tendency toward slower growth of wheat production and consumption will continue from 1979 to 1985 and from 1985 to 2010. Consumption likely will grow more slowly because of lower population and per capita income growth. Slower production growth seems likely, at least for another decade, because of increasing real prices of energy and the expense of extending irrigation. We think it not unlikely that by the 1990s high yielding varieties of wheat will be developed which are less dependent on irrigation, thus easing an important constraint on expansion of wheat production. This is not predictable, however, and we have not tried to take it into account in making our projections of wheat production in the developing countries.

There is, in fact, no firm basis for projecting specific rates of growth in wheat production and consumption in these countries. We assume that production will grow 3.3 percent annually from 1979/80 to 2010. We assume that consumption will grow yearly by 3.2 percent to 1985 and by 3.0 percent to 2010. The resulting projections of wheat production, consumption and imports are shown in Table A-2.

Table A-1 shows that, unlike wheat, production, and consumption of coarse grains grew more rapidly after 1972 than in the preceding five or six years. The behavior of coarse grain production reflects unusually low production in 1972 and 1973 because of bad weather. Production growth since 1972, therefore, cannot be used as a guide for projecting growth after 1979. The fact is that production of coarse grains in the importing developing countries has increased very sluggishly since at least the early 1960s. For the period 1961-1979 production grew 1.3 percent annually. From 1974 to 1979 the annual rate was 1.4 percent.[5]

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[5] These and subsequent figures on production and consumption of coarse grains are from various issues of USDA, Foreign Agricultural Circular Grains.

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TABLE A-2. PRODUCTION, CONSUMPTION, AND IMPORTS OF WHEAT AND COARSE GRAINS IN IMPORTING DEVELOPING COUNTRIES

	(millions metric tons)	
	1979/80	2010
Wheat		
Production	80.8	217
Consumption	133.1	332
Imports	52.3	115
Coarse grains		
Production	117.0	273
Consumption	139.9	399
Imports	22.9	126

Source: 1979/80 from USDA, August 13, 1980. Projections for 2010 described in the text. Changes in stocks assumed to be zero. For wheat includes all countries of Asia, Africa and Latin America except the PRC, Japan, South Africa and Argentina. For coarse grains these countries plus Brazil and Thailand are excluded.

The acceleration in the growth of coarse grain consumption after 1972 reflects a rapid increase in consumption by the OPEC countries. These countries consumed about 11.0 million metric tons of coarse grains in 1968 and about 11.5 million metric tons in 1972. Thereafter, their consumption grew sharply, reaching 18.9 million metric tons in 1978.

While the growth of coarse grain consumption in the OPEC countries was especially dramatic, consumption in developing countries not members of OPEC increased 2.7 percent annually between 1968 and 1978, with even faster growth--4.1 percent--after 1972.

The growth of coarse grain consumption in the developing countries is consistent with their rising income and a consequent shift in diet toward more animal protein. If per capita income in these countries grows as we have projected it, then the proportion of animal protein in their diets should continue to increase, with a consequent steady expansion in consumption of coarse grains. Consumption is not likely to continue to grow at the pace set since 1972, however, if population and per capita income growth in these countries slow down in accordance with our projections. We assume that from 1979/80 to 2010 coarse grain consumption will grow 3.5 percent annually. At this rate of growth consumption would be 399 million tons in 2010.

We think it likely that this rate of growth in coarse grain consumption in the importing developing countries will stimulate coarse grain production to grow faster than in the past. Should production continue to grow at the sluggish pace experienced in 1961-1979 (1.3 percent annually), coarse grain

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imports in 2010 would have to be 220 million tons to satisfy the projected levels of consumption. Valued at 1979 FOB Gulf Ports prices of corn and grain sorghum, this volume of coarse grain imports would cost the importing developing countries approximately $26 billion. The comparable value of 1979/80 imports was about $2.7 billion. We argue below that these countries will be able to finance a substantial increase in their grain imports over the next several decades, and perhaps they would be able to manage an import bill for coarse grains of $27 billion. Long before the bill reached this magnitude, however, it is likely that these countries would seek ways to stimulate their own production of coarse grains so as to keep the bill to more manageable size. We think their search would be rewarded. Until the last few years, most of the effort of international and national food research institutions was devoted to development of higher yielding varieties of rice and wheat. Research on coarse grains was relatively neglected. Recently the balance has begun to shift toward coarse grains, with the Research Center for Improvement of Maize and Wheat (CIMMYT) in Mexico taking the lead. We expect that an increasing proportion of national and international research resources will be devoted to developing new technologies for coarse-grain production. While we cannot now point to any major breakthroughs, we believe the effort will soon begin to pay off in higher rates of coarse-grain production in the importing developing countries. Accordingly, we assume that production will grow 2 percent annually from 1979/80 to 1985, and that the yearly rate will average 3 percent from 1985 to 2010.

Table A-2 shows the projections of production, consumption and imports of wheat and coarse grains in the importing developing countries in 2010. Could these countries afford the projected levels of imports? We think they could. Valued at FOB Gulf Port prices of 1979, average wheat and coarse grain imports of these countries in 1979/80 cost about $11.3 billion. Valued at the same prices, our projections imply that the import bill for wheat and coarse grains would rise to $34 billion in 2010. In 1978, merchandise exports of the importing developing countries were $253 billion (World Bank 1980, pages 124-125). Their imports of wheat and feedgrains in 1979 prices ($11.3 billion) were 4.5 percent of 1978 exports. Exclusive of the OPEC countries grain imports of importing developing countries in 1979/80 were about 7 percent of their merchandise exports in 1978.

Our projections of growth in population and per capita income in the importing developing countries imply that their real GNP will increase 5.0-5.5 percent annually. Export growth likely will keep pace, or approximately so. Our projections of grain imports of these countries, valued in 1979 prices, indicate annual growth of 3.7 percent. Thus the value of these imports would decline relative to the value of exports. Since these countries were able to finance the grain imports of 1979/80 (food aid being relatively minor), it is reasonable to assume that they should be able to finance them also in 2010 when the imports likely will be smaller relative to exports than in 1979/80. Of course, if real grain prices are higher in 2010 than in 1979 the financing problem would be more difficult, and debt service may lay a relatively higher claim on export earnings than in 1979. Moreover, the problem of financing imports will not be equally distributed, those countries with low export-grain import ratios having a more difficult time than countries with high ratios (e.g., OPEC). Nonetheless, we believe the importing

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developing countries as a group will be able and willing to manage the financial burden implied by our projections of grains.

Other Countries[6]

Projections of Wheat Imports--

For Western Europe, Eastern Europe and Japan our projections of wheat imports are in two parts: to 1985 and then to 2010. Per capita consumption of wheat in these countries was constant in the 1970s, and there was a small declining trend in imports, reflecting expansion of wheat production relative to consumption in the European Community (EC). We assume that these tendencies continue to 1985, i.e., that wheat consumption grows only with population and that imports continue to decline at the same rate as in the 1970s. In this case, wheat imports in these countries would be 16 million metric tons in 1985, compared with 17 million in 1979/80 (USDA, August 13, 1980).

For 2010 we make two projections of wheat imports by these countries. One assumes that trends in production, consumption and imports established in the 1970s continue beyond 1985 to 2010. In that case these countries would import 13 million metric tons of wheat in 2010. The alternative projection assumes that the high cost of the EC's Common Agricultural Policy will increase pressure to liberalize the policy, and that after the mid-1980s barriers to imports of wheat and feedgrains will gradually be lowered. We assume this will restrain the growth of wheat production in the EC after 1985 enough to end the slow decline in imports for the group of countries as a whole. Wheat imports by these countries in 2010 thus would be 16 million metric tons, the same as in 1985.

In the 1970s the Soviet Union shifted from being a net exporter of wheat to being a net importer and over the decade imports fluctuated widely, from .5 million metric tons in 1970 to 14.9 million in 1972. The average for 1970-1978 was 5.8 million tons. In the year which ended in June 1980 the USSR imported 11.9 million metric tons of wheat, and the USDA expected the figure for 1980/81 to be 13.0 million tons (USDA, August 13, 1980).

The behavior of wheat imports by the USSR reflected both year-to-year fluctuations in the weather and a political decision by the Soviet authorities to improve the diet of the Russian people. This decision is not likely to be reversed. It suggests that the USSR will continue to be a net importer of wheat.

While the shift of the Soviet Union from being a net exporter of wheat to being a net importer is clear, the annual fluctuations in imports have been so marked that we have no clear basis for extrapolating the trend. Accordingly, we arbitarily assume that in 2010 the USSR will import 12 million metric tons of wheat.

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[6] Western Europe, Eastern Europe, USSR, Japan and the PRC.

From the early 1960s through the mid-1970s the PRC regularly imported 2 to 6 million metric tons of wheat per year (USDA, May 1976). Since the mid-1970s, imports have risen, reaching 8.8 million tons in the year ending mid-1980, with 11.5 million tons expected by the USDA in 1980/81 (USDA, August 13, 1980). This increase in wheat imports by the PRC evidently reflected a generally more open trade policy adopted by the country in the late 1970s. Given the formidable problems faced by the PRC government in feeding its own people adequately, we believe the tendency toward rising wheat imports will continue. We have no sound basis for projecting these imports to 2010, however, so we arbitrarily assume they will come to 20 million metric tons that year.

Projected imports of wheat by Western Europe, Eastern Europe, Japan, the USSR and the PRC in 2010 are shown in Table A-3. Corresponding imports for 1979/80 also are shown for comparison.

TABLE A-3. WHEAT IMPORTS

(Millions Metric Tons)

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		2010	
	1979/80	(1)	(2)*
Western Europe, etc.	17.2	13	16
USSR	12.5	12	12
PRC	10.2	20	20
Total	39.9	45	48

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*Reflects more liberal agricultural trade policies by the EC.
1979/80: USDA, August 13, 1980.

Projections of Coarse Grain Imports--

For Western Europe, Eastern Europe, the USSR and Japan these projections are differences between projections of production and consumption. We make two projections for Western Europe, one assuming a continuation of the EC's Common Agricultural Policy (CAP), and the other assuming that after 1985 the CAP is liberalized, permitting lower grain prices within the community and lower barriers to grain imports. On the assumption that the CAP remains intact, coarse-grain production is projected to increase in accord with the trend established in 1970-1980.[7] In this case production in 2010 would be 139 million metric tons. (Production in 1978-1980 averaged 92.6 million MT).

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[7] The trend equation for this period is $Y = 74.2 + 1.62T$ ($r = .73$) where $T_1 = 1970$. Y is millions of metric tons of coarse-grain production. The source is USDA, August 13, 1980.

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On the assumption that the CAP is liberalized and internal EC grain prices fall after 1985 we project a gradual slowing of growth in coarse-grain production, with a maximum of 110 million MT reached in the 1990s.

Coarse grain production in the USSR is projected to increase in accord with the trend established in 1960-1980,[8] in which case it would be 179 million MT in 2010. (Production in 1978-1980 averaged 93.8 million MT.)

For Eastern Europe we assume that production of coarse grains reaches 65 million metric tons in 1985 and then shows no further increase. Production in this region increased about 1 million metric tons per year on average between 1971 and 1980 (USDA, August 13, 1980). But from 1975 to 1979 the annual increase slowed to about .5 million MT. We assume the slower growth reflects underlying economic and physical constraints affecting feedgrain production in Eastern Europe and that these constraints will persist, allowing only limited additional amounts of production.

The projections of consumption of feedgrains in Western Europe, Eastern Europe, the USSR, and Japan[9] are based on projections of feedgrain consumption per capita. Per capita consumption in all of these areas now is less than in the United States, the greatest difference being between Japan and the United States (.15 metric tons per capita per year in Japan and .67 metric tons in the United States) and the smallest difference being between the United States and Eastern Europe (.53 metric tons per capita per year).[10] In the United States between 1960 and 1978 per capita consumption of feedgrains fluctuated between .57 metric tons (in 1974) and .76 metric tons (in 1972), but there was no trend. The average for the period was .67 metric tons. In Western Europe, Eastern Europe, USSR, and Japan, however, per capita consumption was rising, primarily in response to rising demand for grain-fed animals for meat.

We assume that this trend will continue to 2010, with each region approaching the current U.S. level of per capita consumption of feedgrains. Accordingly, per capita consumption is set at .30 metric tons in Japan, .65 metric tons in the USSR, and .60 metric tons in Eastern Europe. For Western Europe we assume the figure will be .45 metric tons if the CAP continues unchanged. If it is liberalized, however, we assume that lower coarse grain prices would stimulate the demand for grain-fed meat animals, and that per capita coarse-grain consumption would then rise to the current (and projected) U.S. level of .67 MT.

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[8] The trend equation is $Y = 44.6 + 2.63T$ ($r = .83$) where $T_1 = 1960$ and Y = millions of metric tons of coarse-grain production. Sources are USDA, May, 1976 and August 13, 1980.

[9] Japanese production of coarse grains is insignificant. We treat it as zero. Consequently for Japan projected consumption equals imports.

[10] All estimates of per capita feedgrains consumption are for 1978.

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The projections of per capita consumption of coarse grains were multiplied by projections of population in 2010 to derive the projections of total consumption in each region or country. Table A-4 shows the population data.

TABLE A-4. POPULATION IN WESTERN EUROPE, EASTERN EUROPE, USSR, AND JAPAN (millions)

	1976	2010	Average Annual Growth (%) 1970-1976	Average Annual Growth (%) 1976-2010
Western Europe	343.9	381	.55	.3
Eastern Europe	129.2	148	.68	.4
USSR	256.7	304	.90	.5
Japan	112.8	138	1.30	.6

Source: Population in 1976 and growth rates 1970-1976 are from the 1978 World Bank Atlas. The projected growth rates are ours. Another source projects growth rates for the developed countries generally at .45 to .60 in 1995-2000 (Tsui and Bogue).

From the first half of the 1960s to the second half of the 1970s consumption of coarse grains in the PRC increased a little more than 3 percent annually, and until 1978 imports were negligible. In 1978, 1979 and 1980, however, coarse grain imports averaged 2.5 million MT per year (USDA, May 1976 and August 13, 1980).

As noted in the discussion of wheat imports by the PRC, the country evidently adopted a more open trade policy in the late 1970s, and the increase in coarse grain imports after 1977 may be a reflection of this. Whether this portends further growth in imports of coarse grains by the PRC is unknown since Chinese policy in this regard is unpredictable. Given the size of the country, however, the potential for increased imports of coarse grains clearly is substantial if the authorities pursue a policy of upgrading the quality of the Chinese diet. In this connection a member of a team of USDA and farm industry officials who visited China in the spring of 1979 said that the Chinese plan a major effort to increase animal production, and that this "...will dramatically increase the PRC's demand for feedgrains."[11] Although we do not necessarily subscribe to this view we nonetheless believe some increase in PRC imports of coarse grains is likely. Without pretending to a solid base for doing so, we project these imports at 15 million MT in 2010.

Our projections of coarse grains for Western Europe, Eastern Europe, Japan, the USSR and the PRC are shown in Table A-5. Data for 1979/80 are shown for comparison.

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[11] Darwin Stolte, President of the U.S. Feed Grains Council, quoted in Ag World, p. 20

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TABLE A-5. PRODUCTION, CONSUMPTION AND IMPORTS OF COARSE GRAINS, SELECTED COUNTRIES AND REGIONS (millions MT)

	1978/79			2010					
	Prod.	Cons.	Imports	Prod.		Cons.		Imports	
				(1)	(2)	(1)	(2)	(1)	(2)
Western Eur.	92.	110.7	23.8	139	110*	171	255*	32	145*
Eastern Eur.	62.0	71.4	10.7	65		89		24	
Japan	.5	19.0	18.4	--		41		41	
USSR	92.7	106.9	14.3	179		198		19	
PRC	77.0	79.6	2.6	np		np		15	
Total	324.5	387.6	59.8					131	244

np: not projected

*Assumes that the EC's Common Agricultural Policy is liberalized 1979/80 from USDA, August 13, 1980. Changes in stocks not shown.

OILMEAL

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We are interested in U.S. production and exports of soybeans. However, in world markets soybeans are competitive with other sources of oilmeal, such as oilpalm. In recognition of this, USDA data on world production and trade of oilmeal products is given in metric tons of soybean meal equivalent.[12] The ratio of oilmeal weight to weight of soybeans in the United States regularly falls between .78 and .80. We have converted the USDA's data on world trade in oilmeal products to a soybean basis by dividing them by .79. Our procedure, then, for projecting U.S. production of soybeans is in three steps: (1) project world trade in oilmeal products converted to soybean equivalents; (2) project the U.S. share of this trade; (3) project U.S. domestic use of soybeans.

oilmeal

World trade in oilmeal increased rapidly in the 1970s. In terms of soybean meal the annual rate of increase was 7.8 percent between 1972 and 1980 (USDA, November 1977 and December 1979).[13] Since 1973, that is, in the period since the run-up in energy prices, world trade increased at an average annual rate of 9.0 percent. It is unlikely that the oilmeal trade could continue to expand very much longer at such fast rates, and we assume that growth will slow considerably between 1979/80 and 1985, namely to 5.5 percent per year. In this case the world oilmeal trade in 1985, expressed in soybean

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[12] These data appear monthly in Agricultural Outlook.

[13] The trade figure for 1980 is a projection by the USDA based on 1979 production and analysis of previous relationships between production in one year and trade in the following year. In recent years these projections have understated the actual increase in trade.

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weight, will be 72 million metric tons. We expect continued growth in trade from 1985 to 2010, but have no good basis for projecting a specific amount. The demand for oilmeals, particularly those with high protein content such as soybean meal, is stimulated by high and rising income because those are the conditions which encourage high-protein diets. Hence the major consumers of high-protein oilmeals at the present time are the high-income countries. We expect continued expansion of oilmeal consumption in those countries as the demand for meat continues to rise. If the developing countries achieve per capita income growth rates on the order of 3.0-3.5 percent annually, as we have projected, those countries also likely will become important consumers of oilmeal by the end of the century.

At present, none of the high-income countries except the United States are significant producers of soybeans or other sources of oilmeal. We see no reason to expect this to change over the balance of the century. The French have experimented with soybean production, but the results do not suggest that France will become a significant producer of soybeans. Nor does this appear likely for any of the other countries of Europe. Discussions with persons in Europe and the United States knowledgeable about European agriculture indicate a consensus on this issue.[14]

The prospect of rising demand for oilmeal in both developed and developing countries with production confined to a relatively small number of countires implies increasing trade in oilmeal between 1985 and 2010. We assume that the trend toward slower growth in trade which we projected for 1979/80 to 1985 will continue from 1985 to 2010. We make two projections of annual growth for this period: 3.0 percent and 3.5 percent. The higher figure reflects the assumption of liberalization of EC price and trade policies after 1985, leading to faster growth in demand for meat. This would not only stimulate the demand for feedgrains, as noted earlier, but also the demand for high-protein oilmeal as a feed supplement.

Table A-6 shows the projections of world oilmeal trade.

TABLE A-6. WORLD OILMEAL TRADE

(Millions metric tons, soybean equivalent)

1979/80*	2000	
	(1)	(2)
53.9	151	170

*USDA (April 1980, p. 40). Figure is average trade for the two years divided by .79 to convert from soybean meal equivalent to soybean equivalent. Column (1) in 2010 assumes continuation of the EC's Common Agricultural Policy. Column (2) assumes the policy is liberalized.

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[14] In a listing of soybean producers in 1976-1978, Romania and Yugoslavia are the only European countries to appear. Romania was the more important with average annual production of about 200,000 tons. The USSR produced an average of 600,000 tons in the three years (USDA, 1978, p. 133).

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U.S. SHARES OF WORLD TRADE IN 2010

In the four years 1976-79 the United States accounted for 44 percent of world exports of wheat and for 65 percent of world coarse grain exports. Between 1972 and 1980 the U.S. share of world exports of oilmeal varied from 46.0 percent in 1975 to 59.5 percent in 1974. In 1979 it was 53.4 percent and the USDA expected it to be 52.7 percent in 1980. For 1972-80 as a whole the U.S. share averaged 51.5.

We have made two projections of U.S. shares in world exports of these commodities in 2010. One assumes that the U.S. shares remain constant at present levels. The other assumes that the U.S. competitive position in world markets for these commodities weakens so that the U.S. share of each declines.

THE CASE FOR CONSTANT SHARES

The case for believing the United States can maintain present shares is based primarily on recent performance and lack of evidence for a major change in the competitive position of other exporters relative to the United States. Even good production performance in the developing importing countries and the PRC seems likely at most to hold the growth of their imports of grains within manageable limits. We already have indicated our belief that Eastern Europe has little potential for additional production of grains and that the Soviet Union's shift in the 1970s from being a net exporter of wheat to being a net importer will continue. Continuation of the trend in coarse grain production in the USSR, according to our projections, would enable that country to hold imports to modest growth, but would not generate an exportable surplus.

Since the mid-1970s the EC has been a net exporter of wheat, and while the Community has been and continues to be a net importer of coarse grains, its import deficit in these commodities declined from an average of 13.6 million MT in 1970/71 to 9.9 million MT in 1978/79. This performance could be used to argue that the EC could emerge as an important challenger of the United States in world grain markets. We find the argument unconvincing, however. For both wheat and coarse grains the performance of the EC was stimulated powerfully by the Community's Common Agricultural Policy (CAP). The high internal prices adopted under the CAP both restricted the growth of internal demand for grains and gave impulse to production. Continuation of the CAP likely would increase the EC's exports of wheat, and we allowed for that implicitly in our projections of wheat imports of Western Europe and other regions shown in Table A-4. In our projections of coarse grains, we dealt with Western Europe as a whole rather than the EC. Our projections showed that Western Europe would continue to be a net importer of coarse grains even if the CAP stays intact and coarse grain production continues to grow at the rate set in the 1970s.

A-4.

The expansion of wheat exports by the EC does not necessarily mean that the U.S. share of the world wheat trade would be diminished. The emergence

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of the EC as a net exporter of wheat in the 1970s was at the expense of Canada, Australia and the Soviet Union, not the United States. We have not undertaken a detailed analysis of wheat production and costs in these countries so we are unable to explain why they lost ground in the world wheat trade relative to the United States and the EC. Wheat yields in Canada and Australia are well below those in the United States, although yield is a quite imperfect measure of production costs. However, there is nothing in the trend of wheat yields in Canada or Australia to suggest that those countries may improve their positions relative to the United States. As noted in our discussion of wheat projections, the shift of the Soviet Union from wheat exporter to wheat importer apparently reflects a policy decision to upgrade the diet of the Soviet people, a decision unlikely to be reversed.

With respect to coarse grains, the declines in the EC's net imports in the 1970s meant that other countries' exports, probably including those of the United States, increased less than they would have otherwise. However, as in the case of wheat, U.S. exports of coarse grains were less affected by developments in the EC than exports of other countries. Indeed, the U.S. share of world trade in coarse grains increased from 40-45 percent early in the 1970s to 65 percent at the end of the decade.

Thus the reduction in the EC's net imports of coarse grains already is reflected in the U.S. share of world trade in these crops. Continuation of the trend toward smaller net imports in the EC, therefore, in itself would not threaten maintenance of the U.S. share. Acceleration of the trend would be a threat, but we see no reason to expect this. All of the increase in EC production of coarse grains in the 1970s was due to rising yields. The amount of land in these crops was constant, and knowledgeable people in Europe believe there is little potential for bringing in additional land. Yields of coarse grains in the Community were almost 15 percent less than in the United States in the 1970s and rose at a somewhat slower rate.

threaten

In short, there is nothing apparent in the performance of EC production and trade in coarse grains in the 1970s to suggest that the Community might threaten the present U.S. share of world trade in these crops. A detailed study might reveal undercurrents that our admittedly superficial analysis has missed, but in the absence of any such evidence we conclude that the United States could reasonably be expected to retain its 65 percent of world trade in coarse grains.

The ability of the United States in the 1970s to maintain its position in the world oilmeal trade is impressive since in this period Brazil, and more recently Argentina, emerged as major exporters of soybeans and soybean products. At the beginning of the 1970s Brazil and Argentina's share of the trade in soybeans and products was negligible, but by 1977 their exports of these commodities were almost one-third of world trade while the share of the United States had declined to two-thirds (USDA, January 1979, p. 10). The fact that the United States maintained its position in the oilmead trade generally even while losing ground to Brazil and Argentina in soybeans indicates that trade in soybeans and products was expanding faster than trade in other oilseed products.

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Since the mid-1970s the relative positions of the United States and Brazil-Argentina in the world soybean trade appear to have stabilized. Should U.S. exports maintain the current relation to Brazilian and Argentine exports, the U.S. share of the world trade in oilmeal would begin to rise if trade in soybeans and products continues to increase more rapidly than trade in other oilseed products. Should the U.S. share of trade in soybeans and products remain constant, its share of total oilmeal trade also would remain constant even if trade in soybeans and products increases no more rapidly than trade in other oilmeal products. Some combination of a slower rate of increase in soybean trade relative to trade in other oilmeal products and slower growth in Brazilian-Argentine exports of soybeans and products relative to those of the United States also would yield stability in the U.S. share of total oilmeal trade.

On the basis of these considerations, we believe that U.S. exports of soybeans and products could reasonably be expected to continue to take half of total world trade in oilmeal.

THE CASE FOR DECLINING SHARES

The argument that the United States could lose ground in world markets for grains and soybeans is based on an analysis of long-run costs of production in U.S. agriculture (Crosson). The analysis shows that from the end of World War II until the early 1970s real prices (i.e., nominal prices deflated by the cost-of-living index) of U.S. agricultural commodities were declining, reflecting rapid gains in productivity, relatively low prices for fertilizer, pesticides, and fuel, and a declining share of returns to land, capital, and management in total farm income. Since the early 1970s the rate of increase of productivity has slowed, and there is some evidence that this reflects approaching exhaustion of the productivity potential of the technologies on which U.S. farmers have relied since the end of World War II (National Academy of Sciences). Real energy and fertilizer prices in 1978 were 20-to-30 percent higher than in the early 1970s, and there is a consensus that energy prices, and probably fertilizer prices, will be higher in 2010 in real terms than they were in 1978. Finally, the share of returns to land, capital, and management in total farm income now is only some 5 or 6 percent, down from around 25 percent in the late 1940s. The room for further decline, without restricting production, is more limited now than it was then.

The implication of these underlying movements is that the trend toward lower real prices of U.S. agricultural production may slow, or give way to a rising trend. Should this occur, and we believe it likely, then the competitive position of U.S. agriculture in the world markets for grains and oilmeal may be weakened by 2010. We do not argue that this necessarily will occur. New technologies may come into use which would stimulate more rapid productivity growth, and farmers abroad will be as exposed to higher energy prices as American farmers. Still, the likelihood of some deterioration in the U.S. competitive position seems sufficiently high that we ought to take it into account in our projections.

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We have no basis for judging how much the U.S. share of world trade in grains and oilmeal may decline by 2010. We arbitrarily set these shares at 35 percent for wheat, 50 percent for feedgrains, and 40 percent for oilmeal.

U.S. DOMESTIC CONSUMPTION

Our projections for 2010 are found by multiplying projections of per capita consumption by projected population of 279.6 million.[15] Annual per capita consumption of wheat in the United States fluctuated between 85 and 113 kilos between 1963 and 1978. The average was 100 kilos and there was no trend. We project 100 kilos for 2010.

15

As indicated earlier, per capita consumption of feedgrains in the United States was more variable in this period, fluctuating around an average of .67 metric tons, but there was no trend. We project .67 tons for 2010.

Per capita consumption of soybeans increased from 64.4 kilos in 1963/65 to 104.4 kilos in 1977/79, an average annual rate of increase of 2.9 kilos. However, there was a tendency for the rate of increase to slow in the 1970s, the annual growth being 2.1 kilos from 1970/72 to 1976/78. We assume that the tendency for the rate of increase to slow will continue, and that on average per capita consumption from 1977/79 to 2010 will rise 1.7 kilos annually. Soybean consumption per capita in 2010 then would be 159 kilos.

PROJECTIONS OF GRAINS AND SOYBEANS TO 2010

The projections of U.S. production, exports and domestic use of wheat, feedgrains and soybeans are shown in table A-7.

PROJECTIONS OF COTTON

These projections are based on a USDA study by Collins, Evans, and Barry (C-E-B), with certain adjustments by us. The C-E-B projections are for U.S. production, export, and domestic use of cotton in 1985 and 1990. The basic assumptions underlying the projections are as follows (C-E-B), p. 4):

(1) There will be no major wars in the world between now and 1990.

(2) Cotton is viewed as a homogenous commodity; no distinction is made among various staples and grades.

footnote 15

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[15] Found by interpolating between the Department of Commerce's Series E estimates for 2000 and 2025.

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TABLE A-7. U.S. PRODUCTION, DOMESTIC USE, AND EXPORTS OF WHEAT, FEEDGRAINS AND SOYBEANS

(million metric tons)

		2010			
		U.S. share constant		U.S. share reduced	
—	1979/80*	(1)	(2)	(1)	(2)
Wheat					
Production	60.8	98	100	84	85
Domestic use	22.1	28	28	28	28
Exports	38.4	70	72	56	57
Feedgrains					
Production	207.7	354	428	316	372
Domestic Use	153.0	187	187	187	187
Exports	72.6	167	241	129	185
Soybeans					
Production	56.3	120	129	104	112
Domestic use	24.3	44	44	44	44
Exports	29.3	76	85	60	68

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*Averages for the two years, except for soybeans, the years are 1978/79. The differences between production and the sum of utilization and exports is the change in stocks. Exports of soybean meal and oil are expressed in soybean equivalents.

Sources: USDA, August 13, 1980 for wheat and feedgrains. USDA April 1980 for soybeans. In the projections, changes in stocks are assumed to be zero. Projection (1) for 2010 assumes continuation of EC trade and price policies. Projection (2) assumes more liberal trade and lower price policies. Export projections derived by multiplying projections of world trade by U.S. shares. For wheat and feedgrains the projections of world trade are the sums of imports from tables A-2 and A-3 (wheat) and A-2 and A-5 (coarse grains). World trade in soybeans is from Table A-6. Projections of domestic use are described in the previous section.

(3) A synthetic noncellulosic fiber combining the best properties of both cotton and current state of the art synthetics will not become widely available.

(4) A low-cost process that permits cotton to assume all the easy-care and abrasion-resistant properties of synthetics will not become widely available.

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(5) There will be no technological advances in cotton production that permit dramatic yield increases worldwide (such as a multi-adversity seed variety).

(6) Any sustained worldwide food production shortages that might occur would not result in a major shift of land from cotton production to food production.

(7) The price of manmade fiber will increase relative to the price of an equivalent amount of cotton, compared with price averages over 1974-76.

(8) Government policies on fiber consumption, production and trade will remain unchanged from current policies unless specified otherwise in certain markets.

(9) Cotton and manmade fiber will compete in a mature market between now and 1990, especially in developed regions. This means the relative price of cotton and manmade fiber will become more important in determining the market share of each fiber.

Within this framework of assumption two sets of projections to 1990 are developed, one assuming slightly slower growth of world income than in the 1960s and 1970s and the second assuming that income grows 25 percent less than in the 1960s and 1970s. The growth of world demand and supply of fiber is projected in accord with these projections of income growth. Cotton's share of the world fiber market is assumed to continue to decline, as it has for several decades, but at a slower rate than in the 1960s and early 1970s. The main reason for cotton's declining share, according to C-E-B, has been consumer preference for easy-care and abrasion-resistant fabrics competitive with cotton in price.

Projections of world trade in raw cotton are based on analysis of demand-supply balances among developed, developing and centrally planned economies. Under the higher income growth alternative world trade in raw cotton is 20.9 million bales in 1985 and 23.3 million bales in 1990. With the lower income growth alternative trade is 18.8 million bales in both 1985 and 1990. In 1974-76 world trade averaged 18 million bales.

The U.S. share of world trade with the higher income alternative is 27 percent. With the lower income alternative it is 19 percent. In 1974-76 the U.S. share averaged 22 percent. The decline in the U.S. share with slower growth is attributed by C-E-B to the position of the United States as one of the most price-elastic members among major cotton exporting countries for both supply and demand.

Domestic demand for cotton in the United States is projected in two steps: (1) a projection of demand for fiber, based primarily on projections of income and the income elasticity of demand for fiber; (2) a projection of cotton's share of total demand for fiber. The share is expected to decline gradually from 27 percent in 1977 to 22 percent in 1990.

Within the two income growth scenarios alternative projections of U.S. production, exports and domestic production are made in accordance with different assumptions about ratios of cotton prices to prices of polyester fibers. These price assumptions have little effect on the projections, however (C-E-B, p. 23).

The various assumptions made by C-E-B result in a variety of projections of U.S. production, exports and domestic consumption of raw cotton. The production projections for 1990 range from 10.0 million bales to 13.4 million bales. We have elected to base our projection on a figure of 13.1 million for 1990 plus an increment of 2.5 million bales. The 13.1 million bale figure is the 1990 projection of C-E-B corresponding to the higher income growth scenario and a cotton-to-polyester price ratio of 1.15:1. We selected this scenario because it is in line with the World Bank's projections of world income growth (World Bank, 1980). We added the increment of 2.5 million bales because in discussion with one of the authors in the summer of 1980, Collins (of C-E-B) said he then believed that the 13.1 million bale projection was low by about that amount. The reason was that the 13.1 million bale figure did not reflect changed expectations about the growth of demand in the PRC and Western Europe for U.S. cotton exports. Accordingly, we project U.S. cotton production in 1990 at 15.6 million bales, and obtain our projection for 2010 by extrapolation. These and related figures are shown in Table A-8. The projections to 2010 assume that the maximum growth of cotton production after 1990 will be half the annual rate projected by C-E-B for 1976/79 to 1990. At a minimum cotton production would grow only .4 million bales from 1990 to 2010.

TABLE A-8. PRODUCTION, NET EXPORTS AND MILL CONSUMPTION OF RAW COTTON IN THE UNITED STATES (million 480 lb. bales)

	1976/79		1990		2010	
	Millions		Millions		Millions	
	480 lb. Bales	Metric Tons	480 lb. Bales	Metric Tons	480 lb. Bales	Metric Tons
Production	12.6	2.7	15.6	3.4	16-18	3.5-3.9
U.S. Mill Consumption	6.4	1.4	6.8	1.5	np	np
Exports	5.7	1.2	8.8	1.9	np	np

Sources: 1976/79 from USDA, November 1979.
1990 from C-E-B, p. 23. The projections of production and net exports were increased by 2.3 million bales. See text for explanation.
2010. See text for explanation.

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APPENDIX B

TRENDS IN TOTAL AGRICULTURAL PRODUCTIVITY

Table B-1 shows rates of growth in total agricultural productivity over various periods between 1950 and 1972 and between 1972 and 1980. As the years advanced from 1950 to 1960, the annual rate of increase in productivity declined. From 1960 to 1972 it was stable to slightly increasing and from 1972 to 1980 it again declined. It can be argued that between 1950 and 1972 American farmers were engaged in exploiting the high-productivity potential of a new technology consisting basically of fertilizers, high-yielding seed varieties, mechanical power substituting for labor and animals, and to a lesser extent, irrigation. If this statement captures the essence of what was happening, then the decline and subsequent leveling off from 1960 to 1972 in the rate of increase of productivity is plausible. The argument runs as follows. When the new technology began to spread after World War II there was a large difference in productivity between it and the technologies then in use. Consequently the rapid spread of the new technology produced a fast increase also in productivity. By about 1960, however, the substitution of the new for the old technology was substantially completed. Subsequent increases in productivity, therefore, reflected incremental improvements in the new technology rather than wholesale substitution of the new for the old. In this circumstance a slower rate of increase in productivity after about 1960 would be expected.[1]

Whether this account explains the apparent decline in productivity growth after 1972 is not clear, and the issue cannot be pursued here. Indeed, the discussion of trends in agricultural productivity is vexed by serious pro[illegible]s in the measurement of total productivity. There is strong evidence th[illegible]ailure to include quality improvements in inputs resulted in significant underestimates of increases in the quantities of inputs, thus overestimating the increase in productivity.[2] Perhaps more important, the

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[1] By 1960 high-yielding varieties of corn and sorghum had almost 100 percent replaced lower yielding varieties previously in use, and a major part of the substitution of mechanical power for animal power had been completed by the mid-1950s. (Inputs of mechanical power and machinery increased at an annual rate of 6 percent from 1946 to 1955, but by only .24 percent annually from 1955 to 1972. Fertilizer consumption, however, grew even faster after 1960 than it did before that date.)

[2] National Academy of Sciences, 1975, pp. 28-29. Also USDA, Feb. 1980, especially pp. 28-32.

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TABLE B-1. AVERAGE ANNUAL RATES OF GROWTH OF TOTAL AGRICULTURAL PRODUCTIVITY IN THE UNITED STATES

	Percent	Index Points
1950-1972:	2.05%	1.80
1955-1972:	1.91	1.77
1960-1972:	1.62	1.59
1965-1972:	1.64	1.69
1972-1980:	.97	1.08

Source: USDA, Feb. 1981 for 1950-1979. 1980 from Economic Report of the President, 1981.

Note: The growth rates are derived from least squares analysis of annual index numbers of total productivity. Logarithms of these numbers were used to calculate percentage rates of change.

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vast technological changes in American agriculture since the end of World War II make it difficult to construct an index which unambiguously measures the growth of inputs; consequently measurement of productivity change also is ambiguous. The input index currently used by the USDA weights inputs by their average prices in 1971-1973. Wages were much higher in those years relative to prices of other inputs than at the end of World War II, but the amount of labor was sharply reduced relative to those inputs, particularly fertilizer and other agricultural chemicals. Use of 1971-1973 weights gives relatively great importance to labor and hence dampens the rise of the total input index. If price weights of earlier years were used--say 1946-1949--labor would weigh less and other inputs more, and the input index would rise much more steeply than the one used by the USDA. The index of total productivity, of course, would also rise less.[3]

There is no generally satisfactory solution to this index number problem, and the USDA is not to be faulted for not having solved it. The point is that the ambiguity in the productivity index requires that movements in it be interpreted cautiously, and that conclusions about those movements be checked for consistency with other indicators of agricultural performance.

A question arises also about the behavior of the index specifically in the period after 1972. Two features of Table B-2 prompt the question: (1) the fact that most of the growth in total output after 1972 was attributable to crops, and (2) the contrasting behavior in this period of farm real estate and harvested cropland. Farm real estate includes all land in farms, service

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[3] A study by Barton and Durost, cited in National Academy of Sciences, 1975, p. 31, indicated that for the period 1940-1942 to 1956-1958, the index of total inputs increased 23 percent when prices of 1935-1939 were used as weights. When 1957 prices were used the index declined 1 percent.

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TABLE B-2. AVERAGE ANNUAL RATES OF INCREASE IN PRODUCTION AND SELECTED INPUTS IN U.S. AGRICULTURE (PERCENT)

	1960-1972	1972-1980
Production		
Crops	1.6	2.7
Animal Products	1.7	.7
Total	1.6	2.1
Inputs*		
Fertilizer	7.3	3.7
Labor	-4.5	-3.3
Machinery	.3	3.5
Farm real estate	.2	.0
Harvested cropland	-.2	1.8

Source: USDA, Feb. 1981 for 1960-1979; 1980 from USDA, Jan.-Feb. 1981.

Note: Rates are derived from least squares analysis of logarithms of indexes of inputs and production.

*Harvested cropland in 1972-1980. All other inputs are 1972-1979.

buildings, grazing fees, and repairs on service buildings. It thus includes harvested cropland. The amount of harvested cropland increased after 1972 even though farm real estate was unchanged because some farmland previously held idle or in other uses was shifted to crops. It is farm real estate which is included in the index of inputs, but it was the increase in harvested cropland which accounted for most of the increase in crop production, and hence total production, after 1972. It appears, therefore, that because of the way land is handled in the index of inputs, the rise in the index after 1972 was underestimated, with consequent overestimation of the rise in productivity.

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APPENDIX C

ANALYSIS OF TRENDS IN CROP YIELDS

PURE YIELD AND SHIFT EFFECTS

If $\frac{Q^1}{L^1} \div \frac{Q^0}{L^0}$ is the weighted average of yields for a given crop in period 1 relative to period 0 across a number of states, then

$$\frac{\frac{q_a^1}{\ell a^1} \cdot \frac{\ell a^0}{L^0} + \frac{q_b^1}{\ell b^1} \cdot \frac{\ell b^0}{L^0} + \dots + \frac{q_n^1}{\ell n^1} \cdot \frac{\ell n^0}{L^0}}{\frac{q_a^0}{\ell a^0} \cdot \frac{\ell a^0}{L^0} + \frac{q_b^0}{\ell b^0} \cdot \frac{\ell b^0}{L^0} + \dots + \frac{q_n^0}{\ell n^0} \cdot \frac{\ell n^0}{L^0}}$$

is the pure yield increase, i.e., that part of the total increase in average yields from period 0 to period 1 which is attributable to yield increases in each state. It is found by weighting yields in each state in each period by that state's share of land in the crop in period 0.

$$Q = q_a + q_b + \dots q_n$$

$$L = \ell a + \ell b + \dots \ell n, \text{ where}$$

the subscripts refer to states and superscripts to periods.

The pure shift effect is measured in a similar way,

$$\frac{\frac{q_a^0}{\ell a^0} \cdot \frac{\ell a^1}{L^1} + \frac{q_b^0}{\ell b^0} \cdot \frac{\ell b^1}{L^1} + \dots + \frac{q_n^0}{\ell n^0} \cdot \frac{\ell n^1}{L^1}}{\frac{Q^0}{L^0}}$$

In this case the only factor affecting yields is change in each state's share of land in the crop from period 0 to period 1.

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We have calculated these measures with yields in period 0 equal to 100. Consequently, the yield effect minus 100 plus the shift effect minus 100 plus an interaction effect (found as a residual) minus 100 equals the observed percent change in yields.

We calculated these effects for corn, wheat, sorghum, and soybeans in those states which accounted for 80 to 90 percent of total production in the period since 1946-1950. Table C-1 gives the results. The table shows that except for soybeans pure yield effects accounted for 90 percent or more of observed changes in yields. The shift effect for yields of soybeans was negative because of a marked relative shift of land in that crop to Arkansas, Tennessee, Mississippi, and Louisiana, where yields are less than in the Cornbelt, the other principal producing region. Even for soybeans, however, the pure yield effect was by far the most important factor in observed yield changes over most of the period considered.

Perhaps the most significant aspect of table C-1 is the decline in the rate of increase of yields of corn, sorghum and soybeans, and the decline in wheat yields, from 1971-1973 to 1977-1979 compared with the earlier periods shown. This apparent break in trend is generally consistent with the behavior of the index of all crop yields (see table 3-1). We noted that the behavior of that index was generally consistent with the slower shift to land-saving technologies which occurred after 1972. This must also partially explain the behavior of yields of grains and soybeans. We know, however, that weather has a powerful effect on yields in any given year, and that it may also affect the trend of yields. Before we can make statements about the effect of land quality and technology on yields, therefore, we must take out the effects of weather.

PURE YIELD FACTORS: WEATHER

We have estimates of the effects of weather on yields of corn and soybeans in the Corn Belt and of wheat in the Great Plains. The estimates are based on the work of Louis Thompson of Iowa State University (National Oceanic and Atmospheric Administration, 1973 and Thompson, 1977). For corn and soybeans the estimates refer to Ohio, Indiana, Illinois, Iowa, and Missouri. For wheat the estimates are for North and South Dakota, Nebraska, Kansas and Oklahoma.

For corn and soybeans Thompson's analysis covers the years 1891-1976. For wheat the period is 1893-1973. For corn the share of the five states in total land in corn nationwide was about 40 percent in the late forties and fifties, rising to a little over 50 percent in the early 1970s. The share of these states in total soybean land was about 75 percent in the late forties, falling to about 50 percent in the early 1970s. The share of the five wheat states in total wheat land was about 50 percent in the forties and fifties, rising to about 65 percent in the early 1970s. Thompson presents graphs showing that yields of each crop in each set of states were more variable than national average yields but that the trends of yields in the states were very similar to national trends.

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C-3

TABLE C-1. PURE YIELD, PURE SHIFT, AND INTERACTION EFFECTS ON OBSERVED YIELDS OF CORN, WHEAT, SORGHUM, AND SOYBEANS

	1946/50 to 1966/70	1966/70 to 1971/73	1971/73 to 1975/76	1971/73 to 1977/79
Corn				
% change in yields	100.7	21.6	-8.2	8.9
Pure yield	91.0	21.5	-9.1	n.a.
Pure shift	10.5	2.1	.8	n.a.
Interaction	-.8	-2.0	.1	n.a.
Wheat				
% change in yields	66.5	15.0	-5.9	-1.8
Pure yield	65.3	15.7	-6.3	n.a.
Pure shift	1.0	-.6	.5	n.a.
Interaction	.2	-.1	-.1	n.a.
Sorghum				
% change in yields	180.0	15.0	-15.9	.9
Pure yield	172.2	14.5	-16.3	n.a.
Pure shift	-1.3	-.1	.1	n.a.
Interaction	9.1	.6	.3	n.a.
Soybeans				
% change in yields	31.0	6.0	-1.4	8.1
Pure yield	39.2	5.7	-.6	n.a.
Pure shift	-7.8	.6	-.6	n.a.
Interaction	-.4	-.3	-.2	n.a.

Sources: Data on yields are from U.S. Department of Agriculture, Agricultural Statistics, various years. Procedures for calculating pure yield, pure shift, and interaction effects are described in the text.

n.a. means not available because time did not permit calculation of these numbers. However, visual inspection of the data indicates that the pure yield effect accounted for most of the change in yields for each crop between 1971/73 and 1977/79.

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C-4

Thompson relies on a regression of yields against time and weather. Time is measured in years and weather in deviations of monthly precipitation and temperature values in particular crop season months from long-term average values of precipitation and temperature for those months. Time is assumed to measure technology. The analysis gives annual estimates of yields for each state, reflecting technology and weather. The estimates for each state are weighted by the harvested area of the state in a given year to get estimates for groups of states. The weighting procedure eliminates the effects on yields of shifts in the share of each state in total harvested area. The effects of shifts within states to land of differing quality would show up, however, as an effect of technology.

To get at the effects of weather over time, Thompson holds technology constant by selecting a given year, 1973, and then substituting weather variables in his equations for each year in his time series. The result is an estimate for each year of what yields would have been, given 1973 technology and the weather for that year.

We calculated an index of these technology-adjusted yields, setting yields with "normal" (i.e., long-term average) weather equal to 100. Annual differences in this yield index reflect, in principle, the effects of year-to-year differences in the weather. By dividing this yield index for each year into actual yields, we get an estimate of yields for each year which is independent of the effect of weather. Movements in the yield series derived in this way thus reflect only the effect of technology.

Tables C-2, C-3 and C-4 show for corn, soybeans and wheat, the index of weather effects on yields, actual yields, actual yields adjusted for weather, and two sets of weather-adjusted trend values for yields. Examination of weather-adjusted yields in the tables indicates clearly that those series include influences other than technology. With respect to corn, for example, we know that in 1970 yields were greatly reduced by a kind of blight, an occurrence independent of weather, or in any case, not picked up by Thompson's method of measuring weather effects. Nevertheless, for all three crops, weather-adjusted yields are less variable from year to year than actual yields, the expected result. In any case, we have nothing better. Accordingly, we assume that the weather-adjusted series roughly approximate the effects of technology on the trend of yields of corn, wheat, and soybeans.

We ask the following question about the data in the tables: is the behavior of actual yields of corn, soybeans and wheat from 1972 to 1980 consistent with the hypothesis that, after adjustment for weather, the trend of yields in that period was the same as the pre-1972 trend? If the answer is yes we would conclude that there was no change in the effect of land quality or technology on the growth of yields after 1972. If the answer is no we would conclude that yield growth had been affected by changes in land quality, or in technology, or both.

We are handicapped by the lack of data which would permit us to adjust yields for weather for most years after 1972, as the tables indicate. For wheat we can make the adjustment only for 1973 and for corn and soybeans

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TABLE C-2. CORN: INDEX OF EFFECTS OF WEATHER ON YIELDS, ACTUAL YIELDS, WEATHER-ADJUSTED YIELDS, AND TREND VALUES OF WEATHER-ADJUSTED YIELDS*

		Yields (bu. per acre)			
				Trend of Weather-Adjusted	
Year	Index of Weather Effects†	Actual	Weather-Adjusted	Arithmetic	Logarithmic
1950	96.8	49.0	50.6	47.1	50.0
51	95.2	48.1	50.5	49.4	51.1
52	92.8	55.7	60.0	51.7	53.3
53	95.6	51.0	53.4	54.0	55.0
54	92.5	51.1	55.3	56.3	56.7
1955	90.7	51.8	57.1	58.7	58.6
56	97.9	58.4	59.7	61.0	60.4
57	97.4	58.7	60.3	63.3	62.4
58	99.5	64.7	65.0	65.6	64.4
59	99.4	64.0	64.4	67.9	66.4
1960	97.1	64.2	66.1	70.3	68.6
61	102.9	74.2	72.1	72.6	70.8
62	103.6	77.0	74.4	74.9	73.0
63	102.2	80.8	79.0	77.2	75.4
64	98.1	72.6	74.0	79.5	77.8
1965	101.5	85.9	81.1	81.9	80.3
66	96.6	81.3	84.2	84.2	82.8
67	97.8	87.8	89.8	86.5	85.5
68	99.1	88.6	89.4	88.8	88.2
69	100.9	94.0	92.1	91.1	91.0
1970	98.1	77.5	79.0	93.5	94.0
71	97.1	100.6	103.6	95.8	97.0
72	101.4	107.7	106.2	98.1	100.1
73	99.3	101.1	101.8	100.4	103.3
74	78.8	76.7	97.3	102.7	106.6
1975	91.5	97.3	106.3	105.1	110.0
76	93.0	98.0	105.4	107.4	113.5
77		95.6		109.7	117.1
78		109.9		112.0	120.9
79		122.0		114.3	124.7
1980		103.6		116.7	128.7

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TABLE C-2 (continued)

Sources: The index of weather effects 1950-1973 is derived from National Oceanic and Atmospheric Administration 1973, p. 26. The indexes for 1974, 1975 and 1976 are from Louis Thompson (1977). Actual Yields: 1950-1978 from USDA, Agricultural Statistics, various years, 1979-1980 from USDA September 11, 1980. Weather-adjusted yields are actual yields divided by the index.

*For Ohio, Indiana, Illinois, Iowa, Missouri.

†"Normal" yields = 100, 1973 "technology." Values above 100 indicate better than "normal" weather.

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TABLE C-3. SOYBEANS: INDEX OF EFFECTS OF WEATHER ON YIELDS, ACTUAL YIELDS, WEATHER-ADJUSTED YIELDS, AND TREND VALUES OF WEATHER-ADJUSTED YIELDS*

		Yields (bu. per acre)			
				Trend of Weather-Adjusted	
Year	Index of Weather Effects†	Actual	Weather-Adjusted	Arithmetic	Logarithmic
1950	99.8	23.1	23.1	21.8	22.1
51	96.6	23.1	23.9	22.2	22.4
52	97.7	23.1	23.6	22.7	22.8
53	91.9	19.6	21.3	23.1	23.2
54	97.1	22.1	22.7	23.5	23.5
1955	93.6	21.1	22.6	23.9	23.9
56	96.8	23.1	23.8	24.3	24.3
57	98.2	24.7	25.1	24.8	24.7
58	105.7	26.8	25.3	25.2	25.1
59	97.8	25.8	26.3	25.6	25.5
1960	97.5	25.2	25.9	26.0	25.9
61	101.6	27.6	27.2	26.4	26.3
62	102.6	26.8	26.1	26.9	26.7
63	99.8	27.8	27.9	27.3	27.1
64	96.8	24.7	25.5	27.7	27.5
1965	101.0	27.3	27.0	28.1	28.0
66	98.0	27.3	27.9	28.5	28.4
67	97.0	26.5	27.3	29.0	28.9
68	99.3	31.0	31.2	29.4	29.3
69	102.7	31.5	30.7	29.8	29.8
1970	98.4	30.2	30.7	30.2	30.2
71	97.2	31.6	32.5	30.6	30.7
72	100.6	32.3	32.1	31.1	31.2
73	102.6	30.7	29.9	31.5	31.7
74	84.0	24.9	29.6	31.9	32.2
1975	97.6	33.1	33.9	32.3	32.7
76	93.7	29.9	31.9	32.7	33.2
77		35.9		33.2	33.8
78		34.0		33.6	34.3
79		36.4		34.0	34.8
1980		32.7		34.4	35.4

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TABLE C-3 (continued)

Sources: The index of weather effects 1950-1973 is derived from National Oceanic and Atmospheric Administration 1973, page 28. The indexes for 1974, 1975 and 1976 are from Louis Thompson (1977). Actual Yields: 1950-78 from USDA Agricultural Statistics, various years; 1979-80 from USDA, Sept. 11, 1980. Weather-adjusted yields are actual yields divided by the index.

*For Ohio, Indiana, Illinois, Iowa, Missouri.

†"Normal" yields = 100, 1973 "technology." Values above 100 indicate better than "normal" weather.

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TABLE C-4. WHEAT: INDEX OF EFFECTS OF WEATHER ON YIELDS, ACTUAL YIELDS, WEATHER-ADJUSTED YIELDS AND TREND VALUES OF WEATHER-ADJUSTED YIELDS*

Year	Index of Weather Effects†	Yields (bu. per acre)			
				Trend of Weather-Adjusted	
		Actual	Weather-Adjusted	Arithmetic	Logarithmic
1950	96.3	14.0	14.5	14.1	14.7
51	93.7	13.4	14.3	14.8	15.2
52	98.6	16.7	17.0	15.5	15.7
53	92.4	12.6	13.6	16.3	16.3
54	97.9	14.3	14.6	17.0	16.8
1955	95.7	15.3	15.9	17.7	17.4
56	87.5	16.1	18.4	18.4	18.0
57	89.9	19.1	21.2	19.1	18.6
58	110.1	26.8	24.3	19.8	19.3
59	91.9	18.1	19.7	20.6	19.9
1960	104.8	24.9	23.7	21.3	20.6
61	94.7	21.6	22.8	22.0	21.3
62	98.9	23.1	23.3	22.7	22.1
63	93.2	21.0	22.5	23.4	22.8
64	95.3	22.9	24.0	24.1	23.6
1965	96.8	24.1	24.9	24.9	24.4
66	94.1	22.3	23.7	25.6	25.2
67	90.5	21.5	23.7	26.3	26.1
68	100.7	26.5	26.3	27.0	27.0
69	108.7	29.7	27.3	27.7	27.9
1970	95.7	28.9	30.2	28.4	28.9
71	104.1	31.9	30.7	29.2	29.9
72	101.6	30.5	30.0	29.9	30.9
73	108.5	32.1	29.6	30.6	32.0
74		23.9		31.3	33.1
1975		26.7		32.0	34.2
76		25.9		32.7	35.4
77		27.4		33.4	36.6
78		28.7		34.2	37.9
79		32.6		34.9	39.2
1980		27.6		35.6	40.5

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TABLE C-4 (continued)

Sources: The index of weather effects is derived from National Oceanic and Atmospheric Administration, 1973, page 27. Actual yields: 1950-1978 from USDA Agricultural Statistics, various years; 1979-1980 from USDA, Sept. 11, 1980. Weather-adjusted yields are actual yields divided by the index.

*For North Dakota, South Dakota, Nebraska, Kansas, Oklahoma.

†"Normal" yields = 100, 1973 "technology." Values above 100 indicate better than "normal" weather.

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only for 1973, 1974, 1975 and 1976. For these years the differences between weather-adjusted yields and trend values of weather-adjusted yields do not suggest a break in trend after 1972. For each crop, differences as large as those observed in 1973-1976 also occurred occasionally in the years 1950-1972.

Because we cannot adjust for weather after 1976 (1973 in the case of wheat) we adopt a different approach in assessing yield behavior in the more recent years. We ask the following question: given the historical effects of weather on yields, what is the probability that weather could have caused the observed differences between actual yields and the trend values of weather-adjusted yields?[1] In asking this question we assume that weather is the main cause of annual differences between actual yields and the trend values of weather-adjusted yields in 1950-1972, and that other causes are randomly distributed over the period. This, of course, is at best an approximation to the truth. We believe it is a sufficiently good approximation, however, to provide insights into the behavior of actual yields in recent years. If, for example, in every recent year actual yields differed from trend values of weather-adjusted yields by more than the amount observed in any year in the historical record, we would suspect strongly that something had happened to the trend of weather-adjusted yields in recent years.

For those years for which we are unable to adjust for weather we take the difference between actual yields and the trend value of weather-adjusted yields and apply a chi-square test to judge whether the observed differences could be due to weather, given the effects of weather on yields in 1950-1972. For wheat the years considered are 1974-1980. For corn and soybeans they are 1977-1980. For wheat the chi-square test is unequivocal that the observed yield differences could not be due to weather alone.[2] Not only were the differences greater than would be expected on the basis of weather experienced from 1950-1972, but observed yields were less than the trend value of weather-adjusted yields in each year 1974-1980. It is highly probable that there was a tilt downward in the effect of land quality or technology on wheat yields after 1973. We return to this below.

The chi-square test also indicates that the differences in 1977-1980 between actual yields of corn and the trend values of weather-adjusted yields could not be attributable to weather alone.[3] For corn, however, the test result is not as clearcut as that for wheat because in 1979 actual corn

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[1] In considering the question we use differences between actual yields and the arithmetic trend values of weather-adjusted yields. For all three crops the arithmetic trend gave as good a fit to the weather- adjusted yield data as the logarithmic trend.

[2] The test indicated that the probablility of differences as large as those observed if weather were responsible was much less than 1 in 100.

[3] The probability that weather alone was responsible is less than 1 in 100.

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yields exceeded trend yields by a considerable margin. It seems unlikely that this would have happened if there had been a definite downward tilt in the effect of land quality or technology on corn yields in the Cornbelt. We conclude that there may have been such a tilt, but we shall look for additional evidence of it.

The chi-square test indicates that the differences between actual soybean yields and trend values of weather-adjusted yields in 1977-1980 could reasonably have been caused by the weather.[4] There is no convincing evidence, therefore, of a downward tilt in the effect of either land or technology on soybean yields. Indeed if there was a change in quality of soybean land or technology it more likely gave an upward tilt, since actual yields exceeded trend yields in three of the four years 1977-1980. However, we assume no change in land quality or technology effects on the trend of soybean yields in the Cornbelt. Instead we concentrate on corn and wheat, attempting to isolate the effects of land quality and technology on yields of these crops after 1972.

PURE YIELD FACTORS: LAND QUALITY

It is reasonable to assume that for any given level of production farmers will use that land which gives the highest net return per acre. This is not necessarily the land with the highest physical yield per acre, but we expect there is a high correlation between net return and physical yield. Without putting too fine a point on it, we assume accordingly that if land is taken out of production, average yields will rise. If more land is brought into production, average yields will fall.

Measurement of the effect on yields of changes in the amount of land is hampered--in fact made possible--by the absence of data showing yield differences between land in production at any given time and increments or decrements of land between that time and any other. In the absence of such data we have taken two approaches to try to establish limits to the effects of increments or decrements of land on observed yields. In one approach we ask, what would production have been in period t+1 on land in production in t if the trend of yields on that land between t-1 and t had continued. The hypothetical production on this land in t+1 is subtracted from actual production in t+1 and the difference is divided by the increment (or decrement) of land between t and t+1. This gives an estimate of yields on the increment (or decrement) assuming that yields on land in production in t increased between t and t+1 at the same rate as between t-1 and t. One can then ask whether the yield estimate on the increment (or decrement) seems reasonable, for example by comparison with estimated yields on land in production in t. If it seems too low, the implication is that yields on land in production in t grew more slowly between t and t+1 than between t-1 and t.

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[4] The probability that weather alone was responsible is about 15 in 100.

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The second approach begins with an assumption about yields on the increment (or decrement) of land in relation to yields on land in production in t. If the amount of land increased between t and t+1 then we assume that yields on the increment were less than on land in production in t. We then multiply the assumed yield by the amount of the increment and subtract the result from total production in t+1. The result is an estimate of production in t+1 on land in production in t. Dividing that estimate by the amount of land in production in t gives an estimate of yields on that land in t+1. Comparisons of that yield estimate with yields in t are then free of the influence of the increment of land on observed yields, assuming, of course, that the procedure correctly measures that influence.

These procedures, of course, are very rough. Aside from the arbitrary nature of the assumptions about yields on the increment (or decrement) of land, it also is assumed that the gross and net changes in land between t and t+1 are the same. For example, if land in corn is 50 million acres in t and 60 million acres in t+1, the procedure assumes that the same 50 million acres is in production in both t and t+1 with an addition of 10 million acres between the two periods. This may not be the case. It is possible, for example, that 5 million of the 50 acres is shifted to some other use while 15 million acres formerly in some other use are shifted to corn. We really should measure the effect on yields of this 15 million acres, but the procedures we have used cannot do it. The problem probably is not too serious, however, at least for the period between 1972 and 1977-1980, the one of greatest interest to us. Harvested land in wheat and corn in the states we are analyzing increased by a net of about 13 million acres in this period. The amount of land previously in these crops which was shifted to other uses in this period probably was small compared to the increment of land. Hence the difference between the net and the gross increment likely was small.

Changes in the amount of land in wheat and corn in the states of interest here may have significantly affected the pre- and post-1972 trends of yields of those crops. Wheat in particular may have been affected. Between 1946-1950 and 1972 the amount of land in wheat in the five wheat states--North Dakota, South Dakota, Nebraska, Kansas and Oklahome--declined from 36.8 million acres to 25.2 million acres. If in 1946-1950 yields on the 11.6 million acres subsequently taken out of production were 90 percent of yields on the land remaining in production, then removal of the lower yielding land would have contributed a little over 3 percent to the growth of weather-adjusted wheat yields from 1946-1950 to 1972.[5] Between 1972 and 1977-1980 an average of 7.9 million additional acres of land in these states were brought into wheat production, an increase of almost one-third. This reversal in the declining trend of land in wheat may have significantly reduced wheat yields in 1977-1980 below what they otherwise would have been.

There was no significant change between 1946-1950 and 1972 in the amount of land in corn in the five corn states--Ohio, Indiana, Illinois,

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[5] P. Weisgerber (1969) estimated that yields on wheat land held in reserve in the late 1960s were about 90 percent of land in wheat production.

Iowa and Missouri. Consequently, changes in the amount of land could not have affected the trend of corn yields in that period. Between 1972 and 1977-1980, however, the average amount of land in corn in these states increased by 5.4 million acres, or about 18 percent. This may have depressed somewhat the growth of corn yields between 1972 and 1977-1980.

We have used the procedures described above to estimate the effect on wheat and corn yields in 1977-1980 of bringing more land under these crops after 1972. The results are in table C-5. The purpose of the exercise is to estimate the contribution of additional land to the differences between actual yields and weather-adjusted trend yields in 1977-1980 (i.e., the differences between lines 1 and 2 in table C-5). If all of the difference were attributable to the additional land, then yields on that land would have been as shown in line 7, i.e. yields on the increment of wheat land would have averaged 11.9 bushels per acre in 1977-1980, and yields in the increment of corn land would have averaged 71.3 bushels. These figures are so low relative to 1972 actual yields (107.7 bushels for corn and 30.5 bushels for wheat, tables C-2 and C-4) that we can conclude quite confidently that while yields on the increments of land might well have been lower than yields on 1972 land, they could not have been so much lower as to explain all the difference between actual yields in 1977/80 and the trend values of weather-adjusted yields.

Lines 8, 9, and 10 in table C-5 present an alternative approach to estimating the effect of the increments of land in wheat and corn on yields in 1977-1980. For wheat this approach indicates that yields on 1972 land would have been 29.6 bushels in 1977-1980 (line 9), 4.9 bushels less than the trend value of weather-adjusted yields (line 10), and .5 bushels more than actual yields on all wheat land (line 9 minus line 2). This suggests that the increment of wheat land was responsible for only about 10 percent of the difference between actual wheat yields and the trend value of weather-adjusted yields in 1977-1980 (.5 divided by 5.4, the total yield shortfall). This understates the effect of the increment of wheat land on yields because the pre-1972 trend of yields was raised slightly by the reduction in land in wheat in that period. That effect was small, however, as noted above. So the switch from decreasing the amount of wheat land to increasing it probably was not responsible for much more than 10 percent of the shortfall between actual yields and the trend value of weather-adjusted yields. Could the other 80+ percent be attributable to weather alone or did technology also play a role? We return to this question below.

A comparable analysis for corn indicates that the increment of corn land was responsible for about two-thirds of the shortfall in corn yields, given the various underlying assumptions. In the analysis of weather effects on corn yields in 1977-1980 we concluded that weather could not likely explain all the difference between actual yields and trend values of weather-adjusted years. If the increment of land in corn from 1972 to 1977-1980 explains as much as two-thirds of the difference, however, we think it likely that weather could explain the other one-third. It seems unnecessary, therefore, to search further for an explanation of the yield shortfall in the five Cornbelt states in 1977-1980.

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TABLE C-5 ANALYSIS OF THE EFFECTS OF CHANGING THE AMOUNT OF LAND ON YIELDS OF WHEAT AND CORN

		Wheat 1977/80	Corn 1977/80
1)	Yields if pre-1972 trend in weather-adjusted yields had continued	34.5	113.2
2)	Actual yields (bu.)	29.1	107.7
3)	Production in 1977/80 on 1972 land if yields had grown at pre-1972 rate (mill. bu.)	869.4	3452.6
4)	Actual production in 1977/80 (mill. bu.)	963.2	3866.4
5)	Line 4 minus line 3 (mill. bu.)	93.8	413.8
6)	Increment of land 1972 to 1977/80 (mill. bu.)	7.9	5.8
7)	Yield in 1977/80 on increment of land (line 5 divided by line 6 -bu.)	11.9	71.3
8)	Production on increment of land if yield on the wheat increment were 90% of 1972 yield and on the corn increment were 82% (mill. bu.)*	216.9	512.2
9)	Yield in 1977-80 on 1972 land if yield on the increments of land were 90% of yield on 1972 land for wheat and 82% for corn (bu.)	29.6	111.4
10)	The yield shortfall on 1972 land in 1977/80 if yield on increments of land were as stated in line 9 (bu.)	4.9	1.8

*The percentages are from Weisgerber (1969). Wheat yields are averages for Oklahoma, Kansas, Nebraska, South Dakota and North Dakota. For corn the states are Ohio, Indiana, Illinois, Iowa and Missouri.

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The analysis of corn yields has focused on the Cornbelt because in that region we were able to adjust yield data for effects of weather. Corn yields in the rest of the nation, however, moved much as they did in the Cornbelt after 1972, that is, the rate of increase slowed considerably. The amount of harvested land in corn outside the Cornbelt increased 8.3 million acres, or 30 percent, from 1972 to 1977-1980, substantially more than in the Cornbelt both in absolute amount and in percentage. Since our analysis of Cornbelt yields suggests that increased acreage was responsible for a major part of the slowdown in yield growth after 1972, it seems likely that the slower growth of yields outside the Cornbelt also may be attributable largely to the additional acreage.

PURE YIELD FACTORS: TECHNOLOGY

Fertilizer

Table C-6 shows fertilizer use data for corn and wheat. The data are consistent with substantially slower growth in yields of both crops after 1970-1972. From 1964-1966 to 1970-1972 wheat yields increased 1.05 bushels per acre per year. From 1970-1972 to 1977-1979 wheat yields declined slightly. Corn yields grew 3.2 bushels per acre per year from 1964-1966 to 1971-1973 and by 1.4 bushels annually from 1971-1973 to 1977-1979.[6]

In the discussion of the effects of weather and additional land on corn yields in the Cornbelt we concluded that those two factors together could have been responsible for the slower growth of corn yields after 1972. The data in table C-6 suggest, however, that the slower growth in amount of fertilizer applied per acre in corn must also have contributed.

We concluded that additional land did not explain much more than 10 percent of the shortfall in wheat yields in 1977-1980 and asked the question: could weather explain the remaining 80+ percent or did technology also play a role? Table C-6 suggests that technology did play a role but the suggestion is not as strong as in the case of corn. The percentage of land receiving any fertilizer is much less for wheat than for corn, and so is the amount applied per harvested acre. Consequently the contribution of fertilizer to the growth of wheat yields must have been much less decisive than for corn. It follows that the slower growth of fertilizer applied to wheat land after 1972 would have had less impact in slowing the growth of wheat yields after that date.

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[6] We used 1971-1973 for corn instead of 1970-1972 because 1970 yields were severely depressed by an attack of leaf blight.

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TABLE C-6. FERTILIZER USE ON CORN AND WHEAT IN THE UNITED STATES

	Acres receiving (percent)			Amount per receiving acre (lbs.)			Amount per Harvested acre (lbs.)			
	N	P	K	N	P	K	N	P	K	Total
Corn										
1964-1966	88	82	76	73	22	39	64	18	30	112
1970-1972	95	89	84	111	66	68	105	59	57	221
1977-1979	96	88	82	130	68	82	125	60	67	252
Wheat										
1964-1966	48	37	15	30	13	25	14	5	4	23
1970-1972	60	43	16	42	34	37	25	15	6	46
1977-1979	63	42	18	53	37	39	33	16	7	56

Sources: USDA, Jan. 1972, Dec. 1974 and Dec. 1979. The data begin with 1964

N = nitrogen
P = phosphorus
K = potassium

Irrigation[7]

Irrigated production of corn and wheat grew rapidly from 1950 to 1977--4748 percent for corn and 470 percent for wheat--reflecting both an increase in irrigated acreage in these crops and rising yields. However, total irrigated production of corn and wheat was small relative to dryland production. Thus irrigation accounted for only 28 percent of the national increase in corn production and for 12 percent of the increase in wheat production. Yields of irrigated corn and wheat exceed dryland yields, and irrigated yields increased from 1950 to 1977. Consequently, irrigation contributed to rising yields of corn and wheat both because of the expansion of irrigated acreage relative to dryland acreage in these crops and because of rising yields on the irrigated land. Nonetheless, because irrigated acreage in and production of corn and wheat were small relative to dryland acreage and production, the contribution of irrigation to the increase in national yields between 1950 and 1977 was small--13 percent for corn and 7 percent for wheat.

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[7] This discussion is based on Frederick. We deal only with western irrigation, since to date the contribution of eastern irrigation to the growth of yields of crops of interest here has been negligible.

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Reliable data on changes in the amount of irrigated land in corn and wheat since 1972 are not available. However, most of the expansion of irrigated land in these crops for at least ten or fifteen years before 1972 was in the Plains region, particularly Nebraska and Kansas. Discussion with people in the region who follow irrigation suggests little slowdown in the rate of expansion since the early 1970s. If this is true, irrigation would not likely have contributed to slower growth of national corn and wheat yields after 1972. The effect on yields of even relatively large changes in irrigated land would be difficult to detect in any case because of the relatively small contribution of irrigation to the change in national yields.

SUMMARY

There is no evidence of a change in the trend of yields of soybeans in the 5 Cornbelt states after 1972. The observed differences between actual yields and trend values of weather-adjusted yields would easily have resulted from variations in the weather.

Actual corn yields fell short of the trend values of weather-adjusted yields in three of the four years 1977-1980. This cannot be attributed solely to the weather. The expansion of corn acreage after 1972 probably accounts for a substantial proportion--perhaps as much as two-thirds--of the yield short fall. Weather might explain much of the remainder, but slower growth in fertilizer applied per acre after 1972 likely contributed also.

Actual wheat yields in the Great Plains were less than the trend values of weather-adjusted yields in every year from 1974 to 1980. Weather could not have caused this and the expansion of land in wheat probably contributed only about 10 percent to the shortfall. Per acre applications of fertilizer to wheat land increased more slowly after 1972 than before, but the percentage of wheat land receiving fertilizer is too small for this factor to have been very important. There is no evidence to suggest that slower growth in irrigated wheat acreage contributed to the yield shortfall. We are left without an adequate explanation of the failure of wheat yields to grow after 1973 in accordance with the pre-1973 trend of weather-adjusted yields.

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APPENDIX D

PROJECTIONS OF REGIONAL SHARES OF PRODUCTION AND OF REGIONAL CROP YIELDS

REGIONAL SHARES

We noted in Section 2 that there is considerable potential for increased production of irrigated soybeans in the Mississippi Delta, and some potential for expansion of irrigated corn and soybean production in the Southeast. Accordingly, we have projected an increase in the share of the Delta's production of soybeans and in the Southeast's share of both soybeans and corn. Most of the increase would occur after 1985. The Southeast is allocated the greatest percentage increase in production of soybeans because that region has more land in pasture and forest with potential for conversion to cropland than the Delta, both in absolute amount and in relation to its present cropland base.[1] The increased shares of the Delta and the Southeast in soybean production would come at the expense of the Cornbelt, although that region would continue to be by far the nation's leading producer of soybeans. However, as will be pointed out below, our projections of crop production and yields in the Cornbelt imply heavy pressure on the region's supply of cropland by 2010, including land now in forest, pasture, and range with potential for conversion to cropland. Indeed, our projections of crop production and yields imply that the amount of land in crops in the Cornbelt would exceed the present and potential supply by 2010 unless the region's shares of production of some crops decline. We project a small decline in the share of feedgrain production, but we expect a much larger decline in the share of soybeans because of the demonstrated potential for expanded soybean production in both the Delta and the Southeast.

The study by Shulstad et. al. (1980) of irrigation potential in the Mississippi Delta indicates that double-cropping of wheat and soybeans would be one of the more profitable options. If soybean production in the Delta expands as we expect, it is likely that wheat production would increase also. This is reflected in Table 4-1 (Section 4) in the sharp relative increase in wheat production projected for the Delta.

We expect continued growth in the share of the Southern Plains in wheat production, reflecting a process evident for some years, and consistent with the region's relative abundance of land in range and pasture with potential

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[1] Data on potential cropland are from USDA, Feb. 1980. These data are presented in Table 4-6 in Section 4.

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for conversion to cropland. The principal losers in shares of wheat production would be the Cornbelt and Northern Plains, although the later region would remain by far the most important wheat producer in the nation.

We expect the Southern Plains to increase its share of cotton production also, continuing the trend evident over the last couple of decades. However, future conditions are likely to favor the Southern Plains (mainly Texas) relative to Arizona and California as well as relative to the Southeast and the Mississippi Delta. Most cotton production in the two western states is irrigated and will be exposed, therefore, to the increasing constraints on western irrigation noted in Section 2. By contrast only 40-45 percent of the cotton land in Texas is irrigated. Moreover, research in Texas has developed cotton varieties especially well adapted to growing conditions in that state, and which reduce the pest management problem relative to its dimensions in the Southeast and Delta.[2]

Apart from factors already discussed, our projections of regional shares of production also were influenced by comparison of two runs of Iowa State University's model of the agricultural economy of the United States. The runs were done especially for this study.[3] In one of the runs we supplied our projections of crop production and a preliminary allocation of production among the ten USDA producing regions. In the second run we used the same nationwide projections of production, but asked the model to allocate the production among regions. The results of the two runs are shown in Table D-1. If we accept the model's allocation as that which would occur as farmers seek to minimize costs of production and transport among markets, then we would conclude that the regional distribution of production resulting from run 2 is more likely than that resulting from our initial distribution imposed upon the model, represented by run 1. We do not accept the model's distribution as the ultimate truth, but we do believe it should be given some weight. Accordingly, where, in our judgment, our initial distribution differed significantly from the model's distribution we adjusted the initial distribution to bring it closer to the model's. These adjustments were for feedgrains among the Great Lakes, Ohio, Upper Mississippi, and Missouri regions; for wheat among the Upper and Lower Mississippi and the Arkansas-White-Red; and for oilmeal (soybeans) among the Lower Mississippi, the Missouri, and the Arkansas-White-Red. We judged the distribution of cotton in the two runs to be similar enough to need no adjustment.

The various adjustments are incorporated in the regional distribution shown in Table 4-1 (Section 4).

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[2] There is more on this in the discussion in Section 5 of trends in insecticide use on cotton.

[3] The model was developed by Earl Heady and associates. It is a linear programming type which allocates production of major crops among regions in such fashion as to minimize production and transportation costs. The model's structure does not permit allocation of production among USDA production regions. Instead the regions are those shown in Table D-1.

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D-3

TABLE D-1. DISTRIBUTION OF PRODUCTION OF SELECTED CROPS AMONG RIVER BASINS IN THE UNITED STATES IN 2010 (PERCENT)

	Run 1				Run 2			
Region or Basin	Feed-grains	Wheat	Oil-meal†	Cotton	Feed-grains	Wheat	Oil-meal†	Cotton
New England	*	0	0	0	0	0	0	0
Middle Atlantic	2.6	.7	3.1	0	1.4	2.2	3.2	0
South Atlantic-Gulf	6.7	.5	15.8	8.0	4.1	1.9	13.0	9.2
Great Lakes	8.8	5.2	5.7	0	16.1	2.7	1.8	0
Ohio	14.1	4.2	16.7	0	10.7	4.3	20.0	0
Tennessee	.4	*	3.7	0	.3	0	1.5	0
Upper Mississippi	27.1	9.4	24.7	0	37.1	2.4	22.0	0
Lower Mississippi	.1	1.3	14.4	1.2	1.5	7.7	8.6	1.4
Souris-Red-Rainey	.1	8.6	2.9	0	0	8.5	2.0	0
Missouri	25.6	31.3	4.9	0	16.3	34.5	14.2	0
Arkansas-White-Red	7.3	20.4	3.2	9.6	5.5	14.4	9.2	11.1
Texas-Gulf	3.4	1.0	3.9	48.7	4.0	1.7	3.6	44.6
Rio Grande	.5	.2	.2	6.5	.8	*	.1	5.3
Upper Colorado	.1	1.2	0	0	.1	1.5	0	0
Lower Colorado	.1	.6	.1	5.3	*	0	.1	4.5
Great Basin	.1	0	0	0	0	.5	0	0
Columbia-North Pacific	.6	13.2	0	0	.3	14.4	0	0
California-South Pacific	2.1	2.2	.6	20.7	2.2	3.2	.6	23.9

Source: Iowa State University model of the U.S. agricultural economy.

*Less than 1 percent

†Virtually all of this is soybean.

Note: In run 1 the distribution among the USDA producing regions was imposed by RFF. The model then allocated among the regions in the table. In run 2 the model allocated national production among the regions.

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D-4

YIELDS

We expect prices and productivities of inputs to favor more land-using technologies, as they have since the early 1970s. In general, therefore, we take yield behavior in the 1970s as a guide in projecting future yields. For feedgrains, however, we assumed that yields would not grow as rapidly as experience in the 1970s might suggest. The main reason is that we expect the price of fertilizer in the future to behave differently relative to the price of corn then it did in 1973/1979. From 1973 to 1975 the price of nitrogen rose sharply relative to the price of corn and the amount of nitrogen applied per acre of corn declined.[4] From 1975 to 1979 the price of nitrogen declined relative to the price of corn and per acre applications rose. This pattern must have tended to depress corn yields in 1973/75 and then raise them to 1979. As indicated in Section 2, we expect the price of nitrogen to rise relative to the price of corn over the next several decades, in contrast to its behavior in 1975/1979, and that the amount of nitrogen applied per acre of corn will rise less rapidly than from 1975 to 1979.[5] Accordingly, we expect corn yields to rise more slowly from 1979 to 2010 than from 1973 to 1979. Since corn currently accounts for about 70 percent of the land in feedgrains, and for an even larger percentage in our projections, the slower growth of corn yields implies slower growth of feedgrain yields.

We expect soybean yields in the Cornbelt, Delta and Southeast to grow more rapidly than national yields. Our analysis in Section 3 of soybean yields in the Cornbelt indicated that the growth of yields in that region did not slow after 1972, as they did nationwide, and we see no reason to expect different performance in the future. Consequently we projected soybean yields in the Cornbelt to grow to 1985 and 2010 in accord with the arithmetic trend of weather-adjusted yields as shown in Table C-3.

Our discussion of eastern irrigation indicated considerable expansion potential for irrigated soybeans in the Mississippi Delta and, to a lesser extent, in the Southeast. To reflect this we projected a significant increase in soybean yields in those regions, using yield estimates in Shulstad et. al. as a guide. Their study also indicates greatly increased potential for double-cropping wheat with soybeans in the Delta, and this looks promising also in the Southeast. We increased national wheat yields over what the trend since 1973 would suggest to reflect this potential.

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[4] See Table 2-4 for the ratio of nitrogen prices to corn prices. Data on nitrogen applied to corn are from USDA December 1974 and December 1979.

[5] Projections of fertilizer are developed in Section 5.

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